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Detailed Planning of Modern Tramway Systems: Case Helsinki

Thesis submitted for examination for the degree of Master of Science in Technology.

Helsinki, 31 July 2020

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Abstract of master's thesis

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Abstract

Helsinki has a long history of tramways. However, they have a local reputation as a slow mode of transit which only belongs in the inner city. In 2016, the city approved a new master plan which includes nearly 100 km of new tramways to be built by 2050, with the aim of enabling more intense land use. The tramway system is now officially split into "urban" and "rapid" tramways.

The thesis is a case study into the planning process of tramways in Helsinki and aims to determine whether there is an actual difference between the two categories. As a general conclusion, the infrastructure is fundamentally compatible. However, the rapid tramways will be built to higher standards as a system, operating with a higher capacity and speed.

The work also functions as a high-level overview of the current development of Helsinki's tramways in English.

Keywords tramway, rapid tramway, planning, Helsinki

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Diplomityön tiivistelmä

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Tiivistelmä

Helsingin raitioteillä on pitkä historia. Niillä on kuitenkin yleinen maine hitaana liikennemuotona, joka kuuluu vain kantakaupunkiin. Vuonna 2016 kaupunki hyväksyi uuden yleiskaavan, joka sisältää lähes 100 km uusia raitioteitä. Ne on tarkoitus rakentaa vuoteen 2050 mennessä tiivistyvän maankäytön tueksi. Raitiotiejärjestelmä on nyt virallisesti jaettu kaupunki- ja pikaraitioteihin.

Diplomityö on tapaustutkimus Helsingin raitioteiden suunnitteluprosessista. Tavoitteena on selvittää, onko näiden kahden kategorian välillä todellista eroa. Yleisenä johtopäätöksenä voidaan todeta, että infrastruktuuri on pääosin yhteensopivaa. Pikaraitiotiet rakennetaan kuitenkin järjestelmänä laadukkaammin ja niillä tullaan ajamaan suurempia raitiovaunuja aiempaa nopeammin.

Työ toimii myös englanninkielisenä yleiskatsauksena Helsingin raitioteiden tämänhetkisestä kehityksestä.

Avainsanat raitiotie, pikaraitiotie, suunnittelu, Helsinki

Preface

To whom it may concern,

Suffice it to say that I do not belong in academia. The dragged-out process of writing of this somewhat lackluster thesis was the final confirmation of a fact which I personally already knew when I applied for university many years ago. I make a fine transport engineer if I say so myself, but writing essays is not my forte. However, I do not regret the time I spent at Aalto. I have made many wonderful memories and, hopefully, lifelong friends. I consider them to be the most valuable award for this journey. A degree certificate is just a nice bonus.

Even so, hopefully this document can serve as a brief English-language overview of the ongoing transition in the planning practices of tramways in Helsinki. There is by no means too much material available on the topic, and we might need some reinforcements from abroad for the workload in the near future.

Thanks to my colleagues at the City of Helsinki for pushing me to start this thesis.

Thanks to my supervisor Miloš for pushing me to finish it.

Thanks to everyone else in my life for sticking around.

Helsinki, 31 July 2020,

Heikki Salko

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All photographs in the thesis are work of the author.

Abbreviations

HKL – Helsingin kaupungin liikenneliikelaitos – Helsinki City Transport
Autonomous entity under the City of Helsinki which managed all local transit within the city limits until 2010. Currently operates the tramway and metro networks and maintains their rolling stock and infrastructure.

HSL – Helsingin seudun liikenne -kuntayhtymä – Helsinki Region Transport
Joint local authority of Helsinki and several surrounding municipalities, formed in 2010. Procures transit service from operators and manages scheduling, ticketing and passenger information under a single brand. Also responsible for strategic transport planning in the region.

KSV – Kaupunkisuunnitteluvirasto – City Planning Department
Until 2017, department of the City of Helsinki which managed spatial and transport planning.

KYMP – Kaupunkiympäristön toimiala – Urban Environment Division
As of 2017, division of the City of Helsinki which manages spatial and transport planning, infrastructure construction and maintenance, building permits, city-owned real estate, etc. Formed in an organizational reform by merging KSV and several other departments.

1 Introduction

Helsinki has a long history of tramways, with the first lines opening in 1891. However, after World War II, the system remained largely unchanged for several decades while development focused on other modes of transport. In the past decade, trams have again entered the spotlight in Finland, with several ongoing projects in Helsinki and Tampere.

A new master plan was approved for Helsinki in 2016, with the aim of significant growth. At the time of planning, the population within the municipality of Helsinki was approximately 630,000. This is projected to grow by one third, to 860,000 residents, by 2050 (City of Helsinki 2020). Most new development is intended to fill in gaps in the existing urban structure. In particular, highways close to the inner city are to be converted to boulevards similar to the older main streets of the city. All of this implies a considerably higher demand for transport services than currently, while the space available for them is simultaneously shrinking.

The most effective response to such demand would no doubt be constructing underground railway infrastructure. However, expanding the existing metro and railway networks has proven expensive and progressed slowly. Furthermore, even with increased population, Helsinki will remain a relatively sparsely built city on a global scale. The primary focus has thus been put on trams. Specifically, the term *pikaraitiotie* ("rapid tramway") is used for the new lines in the master plan, distinct from the existing *kaupunkiraitiotie* ("urban tramway") network.

1.1 Research questions

The difference between the two categories of tramways remains poorly defined. Therefore, the primary aim of this thesis is to determine what exactly is meant by *pikaraitiotie* and how to plan infrastructure for it. Specifically, the key questions are:

- What are the important design aspects of a modern tramway?
- How do said aspects fit into the planning process in Helsinki?
- Is there a technical difference between urban and rapid tramways?

1.2 Methodology and sources

This thesis is primarily a case study of the tramway system in Helsinki and its design, written from the perspective of an engineer working in the planning organization. The author has worked in various junior positions related to transport planning at the City of Helsinki over multiple separate periods since 2011. Many small details mentioned in the thesis are based on personal observations. Although this method may not be "purely scientific," for lack of a better term, Flyvbjerg (2016) skillfully argues that case studies provide valuable additions to their field of research from outside of academia.

Two expert interviews were conducted for information on other parts of the process. The interviewees were Lauri Kangas, a tram specialist who has worked for the City of Helsinki since 2007, and Otso Kivekäs, the current chairman of Helsinki City Council who has been directly involved with the political processes related to transit in Helsinki since 2011.

Additionally, the author participated in a number of focus group meetings related to tramway planning in 2019.

Finally, key sources include various reports and publications prepared by the City of Helsinki (at both KYMP and HKL) and HSL. Of particular note is the design manual for tramway infrastructure (HKL 2018).

2 Background

2.1 A note on terminology

The terminology surrounding rail transit is not standardized and varies widely between countries and languages. Particularly in English, there are several poorly defined and partially overlapping categories which may be understood differently depending on the location and context.

In North American usage, *light rail* generally refers to a system running mostly on dedicated lanes or alongside highways, albeit with street-legal rolling stock, while *streetcars* or *trolleys* share the streets with motor vehicles. In contrast, *tram* is the general term in British usage. Australia uses a mix of both *tram* and *light rail*. In North America, *tram* is sometimes used for aerial cable cars. *Light rail* can nonetheless be seen as a descriptive umbrella term for the technology, as the infrastructure and rolling stock are considerably lighter in construction than those used on conventional mainline railways and urban rapid transit.

The exact etymology of *tram* is uncertain, but likely traces back to an old Germanic word referring to a wooden log or beam. Those would have been used to form rough tracks for carts in coal mines several centuries ago. From this background, the word has evolved to refer to various kinds of more modern vehicles on fixed guideways. (Liberman 2009.)

In several languages across the world, the English *tram* has been adopted as a loanword, with some adjustments to better fit local orthography or pronunciation. Examples include Dutch, Greek, Estonian, Arabic and Indonesian. (This may be because many of the earliest tramways were located in the United Kingdom.) In many other languages, particularly in Europe, the term *tramway* has been borrowed instead, albeit with a broader meaning which may include even the vehicle. In these instances, *way* has sometimes been replaced by a cognate. Examples include French *tramway*, Spanish *tranvía*, Turkish *tramvay* and Russian *трамвай* (*tramvaj*). From this basis, it can be argued that *tram* is the most universally understood word for the concept.

There are notable exceptions to the trend, however. German primarily uses the native terms *Straßenbahn* (“street-railway”) for fully street-running lines and *Stadtbahn* (“city-railway”) for systems which include segregated sections, often in tunnels. Moving away from direct European influence, the Chinese 电车 (*diànchē*), Japanese 市電 (*shiden*), and Korean 노면전차 (*nomyeonjeoncha*) are derived from words for electrically powered vehicles.

Variants of *metro* are also used in some cities, even though in Europe the word typically refers to a rapid transit system and in North America to the transit service of a metropolitan area as a whole. A prime example is the *Metro do Porto* in Portugal, which is operated with light rail vehicles and integrates newly built tunnels in the city center with old railway lines and on-street segments. Another illustrative case is the *Glenelg tramway* in Adelaide purchasing vehicles originally manufactured for the *Metro Ligero* (“light metro”) lines in Madrid in 2009. They required only minor modifications to enter service. (Fenton 2009.)

Nordic languages have their own terms. The infrastructure is referred to as “track-way” (Swedish *spårväg*, Danish *sporvej*, Finnish *raitiotie*) and the vehicle as “track-wagon” (Swedish *spårvagn*, Danish *sporvogn*, Finnish *raitiovaunu*). In Finnish, it is curious to note that the first part of the compound (*raitio*) is not the same "track" which is otherwise used in reference to rail transport and even tram tracks (*raide*). Nonetheless, both words share the same etymology of originally referring to tracks left on the ground by animals (Aapala 2019).

Local colloquial words and branding add another layer of complexity. Despite having a native term available, many networks in German-speaking areas use *Tram* as a public-facing symbol. In Norway, the common word for a tram is *trikk*, an abbreviated form of the word for "electric" in reference to the mode of propulsion. Yet separate from both this and the more formal *sporvei*, Bergen opened a new line in 2010 under the brand *Bybanen* (literally "City railway"), probably to emphasize the differences from older tramways. In Denmark, new systems in Aarhus and Odense are branded *Letbane* (literally "Light railway"). However, official English translations may be less literal, reflecting the unclear terminology.

In this thesis, the primary term is *tram*, referring to the vehicle which operates on a *tramway*. In contrast, *heavy rail* covers technologies which, as the name suggests, require heavier infrastructure and are not compatible with on-street operation.

2.2 Roles of different transit modes

In the transit system of a large city, different modes cover different needs. Most often, the trunk of the network with the highest demand is served by heavy rail of some sort. Due to its capacity and speed, rail rapid transit can connect large numbers of people over long distances. Feeder lines with fewer passengers and slower speeds connect the trunk to areas not immediately around stations, typically using buses on the regular street network.

There are several ways to classify and evaluate transit. The *Transit Capacity and Quality of Service Manual* (Transportation Research Board 2013), for example, provides several different metrics based on factors such as service coverage, travel time, frequency, reliability and passenger load. Compared to the typical North American context, transit in Helsinki is relatively high quality. Still, regardless of the exact method of classification, it is clear that the existing trams in Helsinki operate very much on the lower end of what the basic technology allows. The service is slow, the network does not reach most of the urban area (there are, of course, other modes which do) and the vehicles are fairly small. Figure 1 positions Helsinki's rail transit in a general comparison of transit modes. The trams should have potential for more.

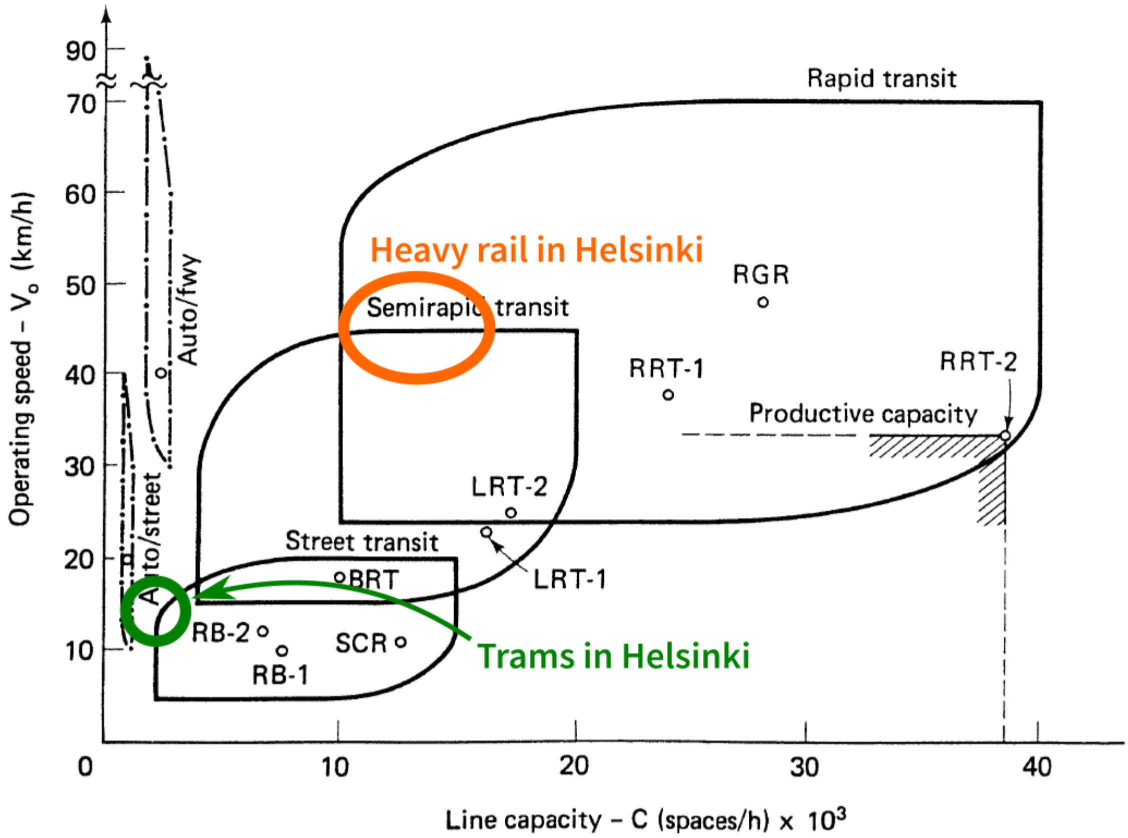


Figure 1. Line capacities and operating speeds of different transit modes (Vuchic 2007, 78) with current rail transit in Helsinki highlighted.

2.3 Case Helsinki

Helsinki, the capital city of Finland, has grown from its origins as a small seaport and administrative hub into a modern metropolis with over a million residents in the urban area. Much of the city is built on small peninsulas and islands jutting out into the Baltic Sea, which presents a challenge to the transportation system.

Local investors saw the potential in rail transport early on. The first horse-drawn tramways began regular operation in 1891, when the city was still relatively small and compact. By 1901, the lines had been electrified, and the network kept expanding for the following decades. In 1944, the municipality took over managing the system. After World War II, the focus shifted to building new suburbs farther out along highways and railway lines. Initially there were intentions to add tramways towards some of the suburbs, but these plans were soon scrapped in favor of a heavier metro system. (Suomen Raitiotieseura ry 2018

The tramway network essentially faced stagnation for decades but managed to avoid total closure. The only other surviving network in Finland, in Turku, was not as lucky and shut down in 1972 to be replaced by diesel buses. Elsewhere in Europe, the trend had been similar, at least until the oil crisis of the 1970s. The situation clearly began to change after 1985 with the success of a new tramway system, built to more modern standards, in Nantes, France (Turnheim and Geels 2019). Since then, dozens of cities across the world have followed suit and opened brand new tramways (UITP 2015).

Also in Helsinki, there was a clear threat that the tramways would be dismantled. This was alleviated with the purchase of a new fleet of rolling stock in 1973, although the primary purpose was merely to replace the most aged trams and maintain the existing system. There was little room for expanding service and indeed, the network saw only minor additions all the way up to the early 2000s. Building and expanding the metro line was prioritized during this era.

The leadership in the responsible organizations was very conservative and it was not always even clear which organization would be responsible for major renewal of the tramways. Urban planning and transit operations were clearly separate departments of the city, and without intense political pressure, nobody would take initiative (Kivekäs 2019). Bluntly put, trams were unfashionable. When politicians did intervene, the results were not necessarily aligned with the goal of efficient transit service. For example, the circuitous route trams take in Western Pasila today was not the planners' first choice (Kangas 2019).

Although there had been various proposals for modern tramways over the years, the decision-makers at transit authorities did not appear interested. As recently as 2014, HSL still based their network plans mostly on the existing or under-construction heavy rail lines together with buses (Kivekäs 2019). However, some level of paradigm shift has occurred in urban planning and its surrounding politics in the 2010s. For the new master plan of Helsinki, several variants of a more rail-based transit network were studied (City of Helsinki 2020). A major factor leading to this was that with the planned intensity of land use, buses could not practically offer enough capacity. Without fully autonomous vehicles, which are presently not close to a mature technology, the labor cost of drivers alone would make bus service too costly, besides the operational issues of running buses at extremely high frequencies.

Adding significantly more heavy rail would not be cost effective, either. The urban structure of Helsinki extends radially from the center in the form of "fingers" separated by unbuilt green zones, with most fingers already served by the existing metro or local railways. Tramways can fill the gaps in coverage at a significantly lower price, costing less than half to construct per kilometer compared to the metro (City of Helsinki 2020).

As a result, the City Plan 2016 outlines a major expansion of the transit network using primarily trams. Even more specifically, the plan makes a distinction between "rapid" and "urban" tramways. The two types will remain based on the same underlying technology and largely compatible with each other, but there are cultural reasons to enforce a difference.

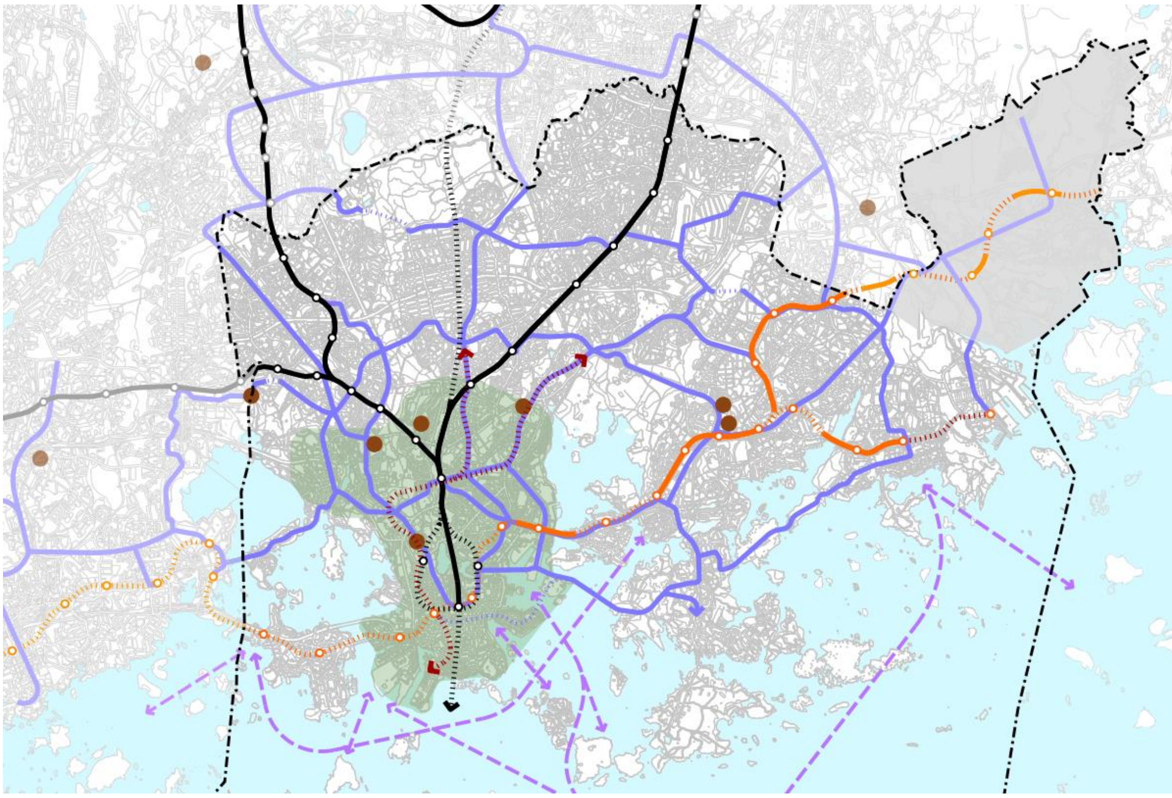


Figure 2. Proposed transit network for Helsinki in 2050 (City of Helsinki 2020). Solid purple lines represent potential rapid tramway corridors, some of which are now progressing, while the area shaded in green will continue to be served by urban tramways.

Within Helsinki, the existing network corresponds to a popular concept of the inner city (*kantakaupunki*): it is urban where there are tramways, and tramways likewise only belong in the urban city center. A proposal for an architecture prize even describes how, when the district of Pikku-Huopalahti was built in the 1990s, a decision was made to “allow an extension of the tramway” which would “[imbue] the residents with a sense of belonging to the urban core” (KSV 2002). It is debatable whether this goal was ultimately achieved.

The border is clear even on the above map. This is understandable, considering that the extent of the network remained largely unchanged for the latter half of the 20th century, and as such formed a stable mental image for most locals. The most recent expansions have not extended significantly outwards, either.

The current tram lines in Helsinki are among the slowest in Europe, with operating speeds averaging as little as 14 km/h (KYMP 2017b, p. 12). As there are currently no active tramways anywhere else in the country, this slowness largely defines the entire concept of “tram” in Finnish public consciousness. Explicitly calling the new lines “rapid” seems to be an attempt to break away from this preconception in a way that is meaningful to everyone.

The initial development of the rapid tramway concept has occurred in tandem with *Raide-Jokeri*, which is by far the largest tramway project in Helsinki in decades, possibly ever until now. As the route orbits around the city center and there will initially be no track connection to the old network, it provides the perfect opportunity to demonstrate a new technology. *Kruunusillat*, another major project stretching eastwards from the city center on a series of bridges, has also been co-opted as its development has progressed.

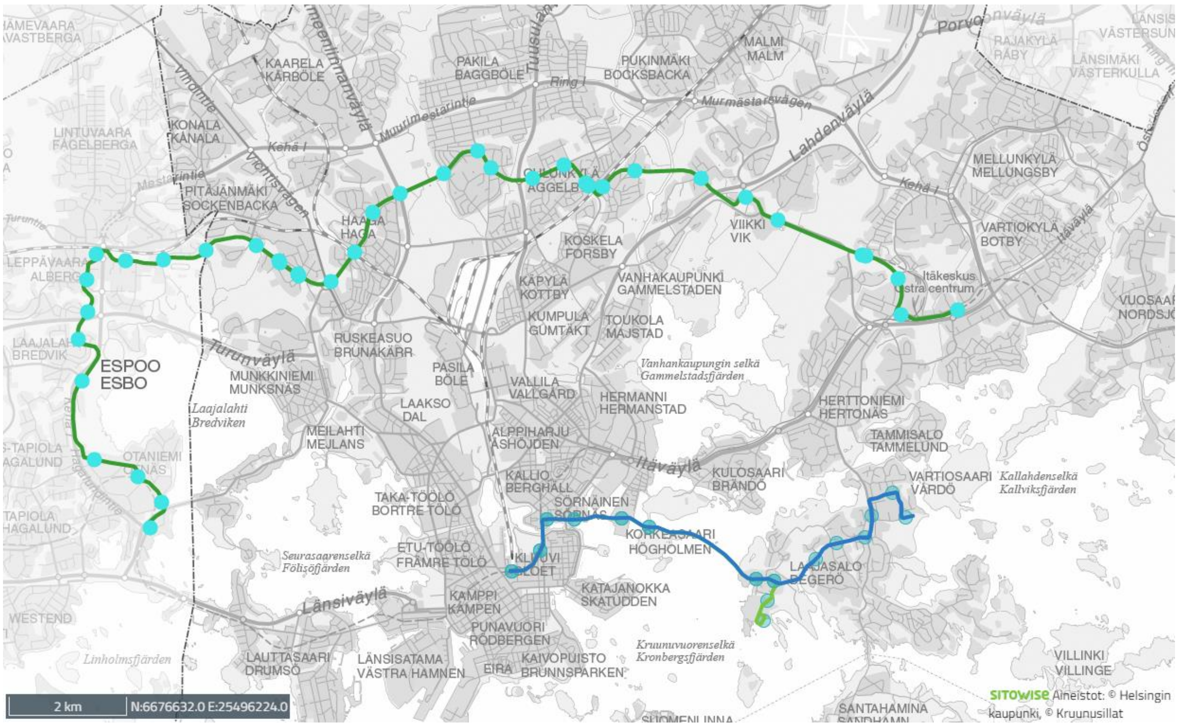


Figure 3. Alignments of Raide-Jokeri (above) and Kruunusillat (below). (Source: City of Helsinki.)

3 Results and discussion

3.1 Rapid tramways

The term *pikaraitiotie* has existed in Finnish professional jargon for decades now. Although "rapid tramway" is not a common term in English, direct equivalents exist elsewhere: *sneltram* in Dutch, *snabbspårväg* in Swedish. Languages of the former Eastern Bloc are notable here, perhaps reflecting the use of similar technology in the area. For instance, Polish *szybki tramwaj* and Ukrainian *швидкісний трамвай* (*švydkisnyj tramvaj*) mean quite literally the same thing. There is thus precedent for the term, but its widespread use in planning is a recent development and appears to be limited to Helsinki. It is particularly interesting that the Tampere tramway, developed at a similar time, is officially called just *raitiotie* without any prefixes. Clearly there is no need to distinguish it from anything else.

Beginning with a 2015 brochure, Helsinki advertises the rapid tramway concept to the public with three key features: it is *efficient*, *comfortable* and *safe* (KSV 2015). The adjectives are intended particularly in contrast to buses, which currently provide most of the transit service on future rapid tramway corridors, but also to traditional trams. The stated aims include an operating speed of 25 km/h, an average stop spacing of 800 meters and direct lines. These numbers are nearly doubled from the respective figures for the current tramway network, which does imply a new kind of infrastructure.

Despite certain differences, the basic technology remains identical between the two categories. During the early planning of Raide-Jokeri, using different technology for rapid tramways was given some consideration. The primary examples were standard gauge (1435 mm) track and wider (2.65 m) vehicles in line with modern European standards, which could result in marginally higher capacity or passenger comfort. However, the decision was reached that compatibility with existing infrastructure will outweigh any possible advantages. The only obvious difference is in the rolling stock which will consist of bidirectional units, thus eliminating the need for turnaround loops at line termini. The new trams will also receive a unique color scheme to distinguish the mode in the streets.

Table 1. Key technological features of urban and rapid tramways.

Feature	Urban tramways	Rapid tramways
Track gauge	1000 mm	
Electrification	Overhead 600 V DC (to be increased to 750 V)	Overhead 750 V DC
Width of trams	2.4 m	
Length of trams	27 m	35…45 m
Maximum speed	70 km/h	
Bidirectional operation	No	Yes

There are two major conclusions to be drawn from table 1:

Firstly, all new tramways in Helsinki should be planned and built according to the same basic standards, which are drafted primarily for rapid tramways. They will constitute the vast majority of new lines by length and there is no particular reason to aim for lower quality in the city center. Exceptions can always be made if following the full standards is impossible. Partially to this end, HKL has published a design manual for tramway infrastructure in 2018. It could be updated and expanded upon.

Secondly, if the delineation between urban and rapid tramways is not a simple matter of infrastructure, the two can overlap. The Kruunusillat project is an example of this. Although new infrastructure is being built to full rapid tramway standards outside the city center, the service will be brought into the very core on existing tracks which will continue to be used by urban lines as well. Therefore, if there are to be clear criteria for a rapid tramway, they must refer to the service across an entire line and not to sections of track. HSL is currently developing the service concept but details remain to be seen (Kangas 2019).

An even clearer example of the overlap is the Kalasatama tramway project. It is situated plainly at the interface of the two categories in a way which complicates its design. On one hand, it provides local service within the Kalasatama district, much like traditional urban tramways. The planned alignment along residential streets has been designed accordingly, since that was intended as its primary purpose before the current master plan. On the other hand, the line is now also intended to serve as a rapid link between the new Kruunusillat connection and the transport hub at Pasila. These two purposes imply rather different design parameters, particularly stop spacing, and necessitate a compromise of some kind.

In any case, since radial rapid tramway lines must reach the city center to be useful, they will utilize parts of the existing network. Some modifications to the old infrastructure may be necessary. The corridors which will be "taken over" are highlighted in figure 4.

Figure 4. Rapid tramway corridors (in blue) overlaid on the urban tramway network of 2025. The Kalasatama tramway is shown dashed due to its ambiguous status. (KYMP 2017)

3.2 Types of tramway infrastructure

According to Vuchic (2007, p. 47), transit modes can be categorized based on three basic characteristics: right-of-way category, system technology and type of service. It has already been established that the basic technology does not vary between urban and rapid tramways. The two are fundamentally compatible. Service is a separate issue, so the remaining technological characteristic is the right-of-way (ROW). Vuchic splits ROWs into three categories, denoted A, B and C. More nuance could be useful for detailed analysis of a network, but at a basic level, this describes clearly what kind of conditions there are for operations.

3.2.1 Traditional mixed traffic (ROW C)

The first tramways in the 19th century were largely built by embedding metal rails in the middle of existing cobblestone or gravel streets with no further segregation. This was a cheap and simple solution, and traffic volumes were typically low enough that a more sophisticated design was not necessary. Pushcarts and horse-drawn carriages mingled in the middle, while pedestrians used paved or wooden sidewalks where available. Adding trams to the mix was a natural progression, particularly as they too were initially powered by horses before widespread electrification.

Unfortunately in the 20th century, as carriages gave way to ever-increasing numbers of automobiles and cobblestones to asphalt, sharing the space became a liability. Trams became stuck in traffic, slowing their operating speed to a crawl, while the passengers had to negotiate their way on and off through a stream of other vehicles with no separate platforms to help. Conversely, other drivers might see the trams as a hindrance to themselves.

In most modern tramway systems, these issues have been resolved on the main corridors following wide avenues. On smaller streets, however, there is often physically no space for proper segregation. Shared lanes are overall a relatively cheap solution in an urban environment, as they minimize the necessary land area. The primary drawback is congestion, so they only work well in locations without too much traffic. Disruptions are also caused by on-street parking. A poorly parked car can block trams on the adjacent lane entirely. Removing parking or restricting access by other vehicles are easy solutions in terms of engineering, but often very difficult politically.

For pedestrian access, ROW C has some benefits. Platforms can be integrated directly with sidewalks, eliminating the need for additional crosswalks to reach an island in the middle of a street. If driven slowly enough, trams can even travel right through pedestrian zones. Their movements are fully predictable thanks to the fixed position of the tracks, so safety is not compromised. However, this does result in extremely low operating speeds and should thus only be done near the most significant destinations for passengers, where it is worthwhile to bring the service very close.

Figure 5. Right of way category C. Tramway shares lanes with other vehicles, flanked by on-street parking. Platforms at stops extend all the way to the tracks. Kaarlenkatu, Helsinki.

3.2.2 Full segregation (ROW A)

At the opposite end of the spectrum, rail lines can be fully grade-separated and protected from essentially all disruptions caused by external factors. This is the norm on heavy rail serving long-distance trains or subways but quite rare on tramways. In North America, light rail lines are sometimes built along existing corridors used by highways or freight railroads, which are themselves largely segregated. Road crossings may be at-grade, but they are sparsely spaced and often protected by alarms and gates.

While full segregation enables fast and smooth operation, it is usually considerably more expensive to build than the alternatives. On ground level, only a basic foundation is needed under regular rails. Bridges take up large amounts of concrete and other materials, while also requiring a strong foundation and space on the ground for support columns. Underground tunnels free up space on the surface but are yet more costly to construct, particularly due to modern safety regulations which mandate extensive facilities for evacuating all passengers in case of fire. Nevertheless, tunneling some sections of the rapid tramway lines may yet prove worthwhile for reasons of speed and capacity (Vainikainen 2019).

The space benefit is also partially negated by the ramps required to transition between different elevations, although these can be built at locations where the intrusion is minimal. For example, the entrance to a tunnel would ideally be excavated into a vertical cliff face or integrated in the lowest level of a building.

The level of service suffers somewhat as accessing the stops becomes slower. By its nature, a route without intersections with other traffic will be located separate from other functions in an urban area. If the separation is achieved horizontally, the line will be away from other amenities for its users, increasing walking distances. If vertically, i.e. with a bridge, cutting or tunnel, it will be necessary to use stairs, escalators or elevators to get to and from platforms. If the local topography is suitable, a gently sloping ramp may suffice. In any case, a larger proportion of travel time is spent to access the service than with street-level infrastructure. Faster operating speeds counter this downside, but only on comparatively long journeys.

There are no sections of ROW A on the existing urban tramway network in Helsinki. When they are eventually introduced by rapid tramway lines, they will likely become one of the clearest defining characteristics of the concept for the general public.

Figure 6. Right of way category A. Tracks laid separate from the street on bare ballast at the edge of a wooded area. Rieväkatu, Tampere.

3.2.3 Light segregation on street level (ROW B)

The compromise between operating in mixed traffic and building expensive dedicated infrastructure is, of course, reserving parts of regular streets exclusively for transit. At its most basic, this can be achieved with painted lane markings. However, adding some kind of structural separation increases the reliability, as other vehicles can no longer accidentally stray into the lane. In Helsinki, this is generally done by raising the tramway slightly upwards with curbs. The vast majority of newly constructed or upgraded tramways in the city currently follow this style.

Figure 7. Right of way category B. Tramway separated from car lanes by a curb. Mannerheimintie, Helsinki.

Surfacing the tramway differently from surrounding lanes further increases the effect. An even bigger benefit could be gained by highlighting tracks at intersections (Saari 2019). Internationally, there appear to be two primary styles for median tracks: plain, exposed ballast under the tracks as on mainline railways, or embedding the tracks in grass. In Helsinki, however, the separated tramway is usually still paved, although not necessarily with asphalt. Even "green" tracks consist of bricks with holes for vegetation to grow through. This might slightly ease maintenance, but the primary reason is that tramways also function as lanes for emergency vehicles. Given that traffic congestion in Helsinki is very minor in a global comparison (HERE 2020), the access may not be strictly necessary like in some other cities, but it is the traditional norm and the downsides are mostly aesthetic.

The accessibility of stops in ROW B is likewise a compromise. As they are situated directly in the street, the distance to the platforms is not prohibitive. However, depending on the number of lanes and traffic volumes surrounding the stop, enabling safe pedestrian routes may require additional infrastructure. In Helsinki, many of the key sections of the tramway network are located on arterial streets with 2–3 lanes in each direction around the tracks. Safely crossing such a carriageway is only possible with traffic signals for many pedestrians. Since most stops are located adjacent to major intersections, this is already the case. The recently approved planning guidelines for pedestrian crossings (KYMP 2019) strongly recommend traffic signals or potentially, low speed limits enforced with speed bumps. At least currently, there are no examples of the latter in practice.

Since the platform is a self-contained island in the middle of the street, it must be wide enough to support sufficient passenger volumes and access with wheelchairs or other equipment. Narrow platforms are especially unsuitable for maintenance during a snowy winter (Jensen 2017). This poses problems, as many streets are too narrow to fit enough additional width for a full-size platform (current recommendation 3.50 m), particularly if there are two directly opposite each other. Some solutions include staggering the platforms lengthwise on opposite sides of an intersection or sharing a part of the cross section which is otherwise used for planting trees. As the new rolling stock for rapid tramways is bidirectional with doors on both sides, it would also be possible to build center platforms which require less overall width than two separate side platforms. However, it appears this is still avoided to maximize the compatibility with older trams.

Figure 8. Right of way category B. An ambulance utilizing a tramway separated from car lanes with fences. Yusufpaşa, Istanbul, Turkey.

Figure 9. Right of way category B. Tramway separated from car lanes by grass strips and trees. Teiskontie, Tampere.

3.2.4 Combination of categories

One of the largest benefits of trams compared to other transit modes is that they are not dependent on a uniform style of infrastructure for the entire network. In principle, as long as there are tracks, a tram can proceed. As a hypothetical example, it is possible for one line to use an underground tunnel (ROW A) in the city center, continue in the median of an arterial street separated by a curb (ROW B), diverge from the street to run through a park without access to other vehicles (ROW A or B depending on level of segregation), and finally share quiet residential streets with cars (ROW C) before reaching a terminus.

In contrast, buses require a paved carriageway on their entire route. This is a benefit when lines can use regular streets with no additional infrastructure needed, but dedicated transit routes must also be built to the same standards. They can appear rather intrusive around otherwise lush areas of greenery, which limits politically acceptable alignments. Reliably restricting access by other motor vehicles is likewise challenging.

Other, heavier rail vehicles could in theory work anywhere similar to trams, but there are two major issues: large turning radii make it nearly impossible to fit the tracks in tight urban spaces, and the electrification systems are unsafe in locations accessible to pedestrians. Finnish mainline railways employ a catenary at a high voltage, which poses a risk of electrical arcing if approached too closely. The metro in Helsinki has a third rail close to track level, which would additionally be highly impractical in a public area.

Due to their flexible infrastructural requirements, trams appear to be an ideal solution for transit in locations which do not absolutely require the high passenger capacity or operating speeds provided by heavy rail.

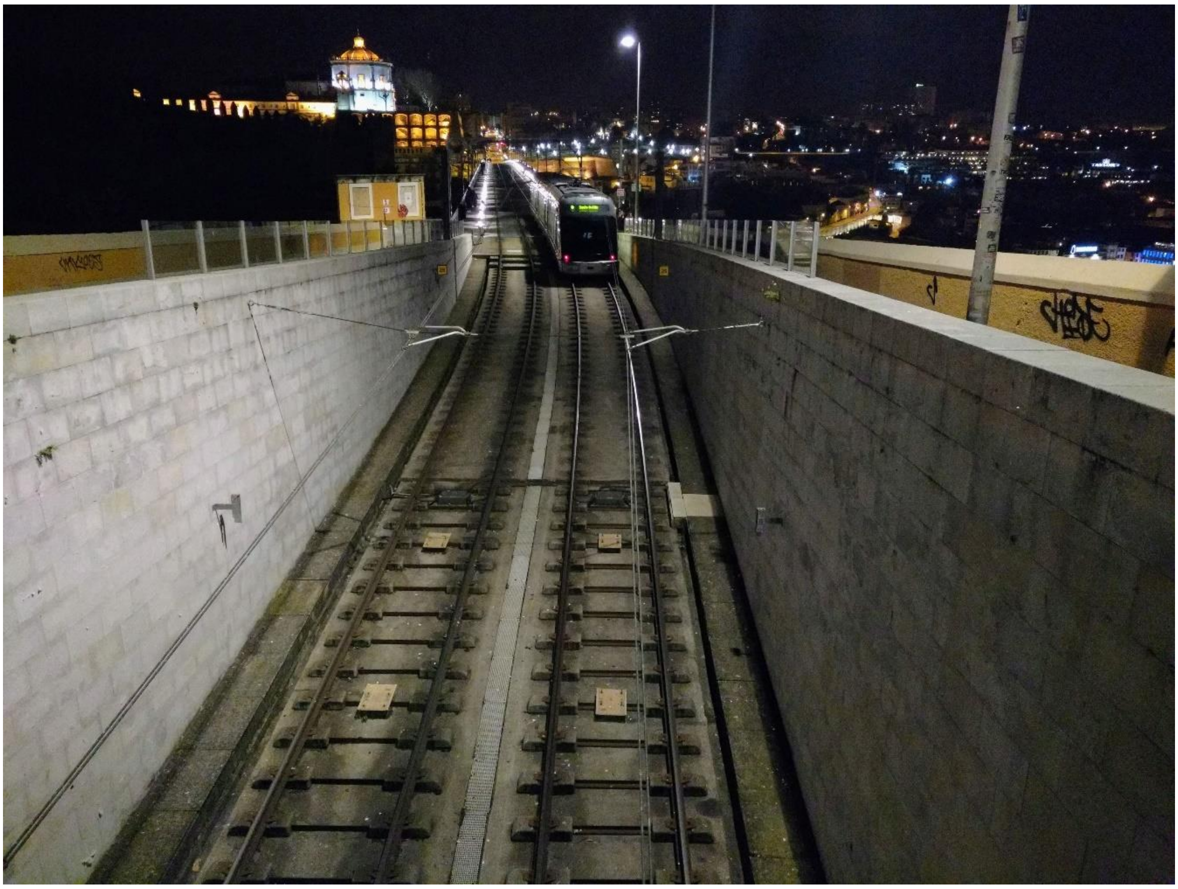


Figure 10. A tram exiting a tunnel (ROW A) directly onto a bridge shared with pedestrians (ROW C). Ponte Luís I, Porto, Portugal.

3.3 Working backwards from service to design

For a user of the system, fine technological details should not matter. What matters is the service they enable. Therefore, planning of infrastructure and rolling stock should follow a predefined transit service and not vice versa. Of course, the desired service patterns can evolve over time and must generally follow the available infrastructure at that point. It is beneficial to have some redundancy to enable alterations in service at least on a temporary basis during a disruption. For more permanent changes, it may be justifiable to modify the infrastructure as well. As a practical example from recent years, an additional platform was constructed at the Kuusitie tram stop to enable the use of its turnaround loop as a terminus in normal service.

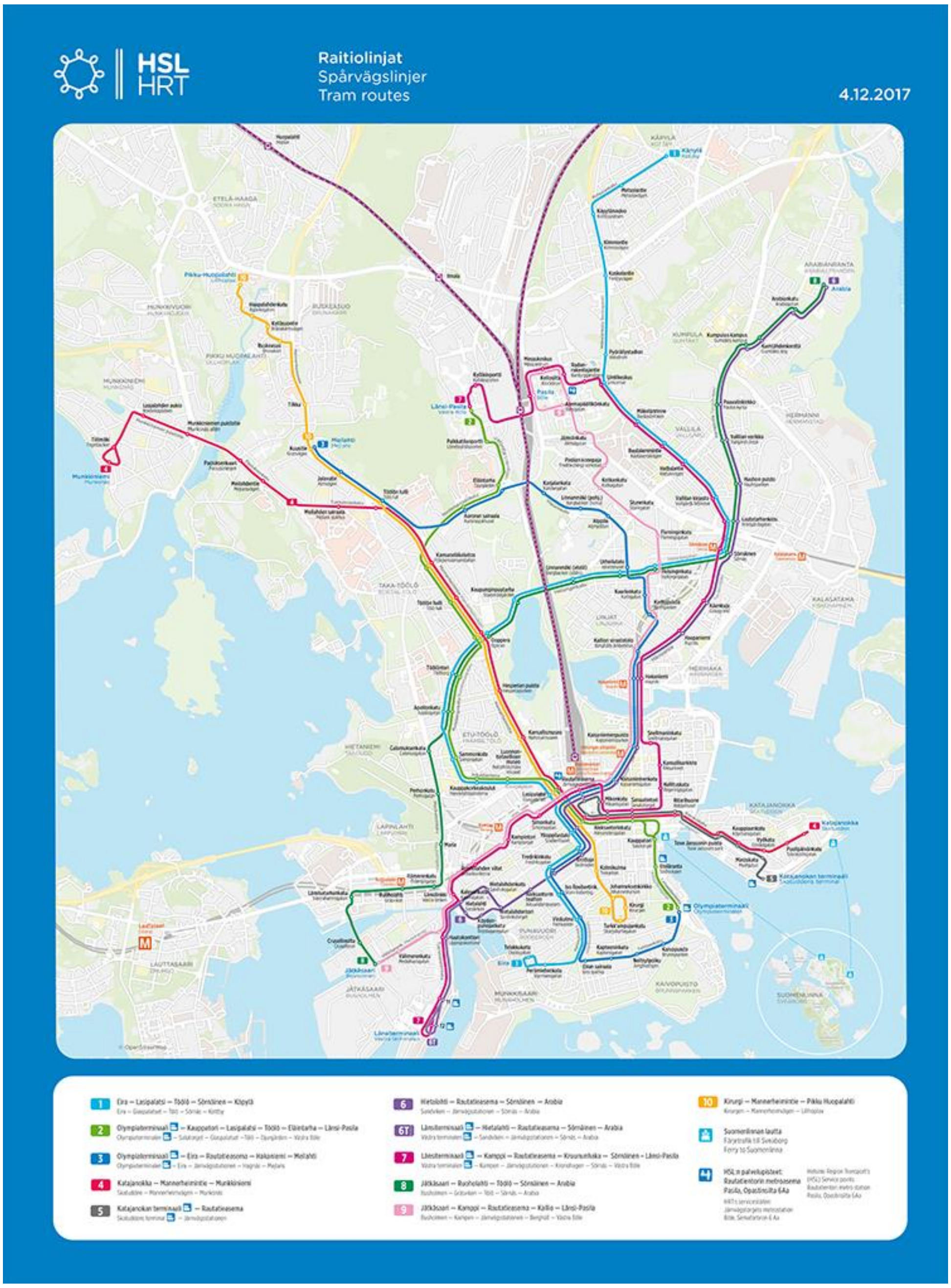


Figure 11. Map of the tram service in Helsinki in late 2017, following a major reorganization of the network. (Source: HSL.)

Since the new rapid tramways are essentially being built from the ground up, there is an opportunity to design their infrastructure around a desired service. This is being done; for example, the foundations of tracks are built to a higher standard than traditionally. However, the parameters to design to should be chosen carefully. In the Raide-Jokeri project, an operating speed of 25 km/h was set as an important criterion early on. Trying to reach it at all costs may have resulted in other important aspects like passenger comfort suffering slightly (Kangas 2019).

Jarrett Walker (2011) outlines one potential framework for evaluating the overall usefulness of a transit service, consisting of seven demands from the perspective of the passenger:

1. It takes me *where* I want to go.
2. It takes me *when* I want to go.
3. It is a good use of my *time*.
4. It is a good use of my *money*.
5. It *respects* me in the level of safety, comfort, and amenity it provides.
6. I can *trust* it.
7. It gives me *freedom* to change my plans.

Purely maximizing the operating speed addresses demand 3 but does not necessarily affect the others in any way. A more holistic view should be taken in the early stages of design.

The following sections examine the relationships of certain characteristics of transit service to infrastructure and rolling stock.

3.3.1 Passenger capacity

Table 2. Hourly passenger capacity of a line with various vehicle types and headways. Adapted from HSL (2016) and Vainikainen (2019).

	Headway [min]		10	7.5	6	5	4	3	2.5	2
	Trips per hour		6	8	10	12	15	20	24	30
	Spaces per trip									
Vehicle type	Peak	Design	Total spaces per hour							
Bus, 2 axles	56	48	288	384	480	576	720	960	1152	1440
Bus, 3 axles	78	66	396	528	660	792	990	1320	1584	1980
Bus, articulated	105	89	534	712	890	1068	1335	1780	2136	2670
Tram, high floor	142	121	726	968	1210	1452	1815	2420	2904	3630
Tram, 27 m	151	128	768	1024	1280	1536	1920	2560	3072	3840
Tram, 35 m	*~180*	*150*	*900*	*1200*	*1500*	*1800*	*2250*	*3000*	*3600*	*4500*
Tram, 45 m	*~250*	*210*	*1260*	*1680*	*2100*	*2520*	*3150*	*4200*	*5040*	*6300*
Tram, 60 m	*~350*	*300*	*1800*	*2400*	*3000*	*3600*	*4500*	*6000*	*7200*	*9000*
Metro, 90 m	708	602	3612	4816	6020	7224	9030	12040	14448	
Local train, 75 m	420	336	2016	2688	3360	4032	5040			
Local train, 150 m	840	672	4032	5376	6720	8064	10080			
Local train, 225 m	1260	1008	6048	8064	10080	12096	15120			

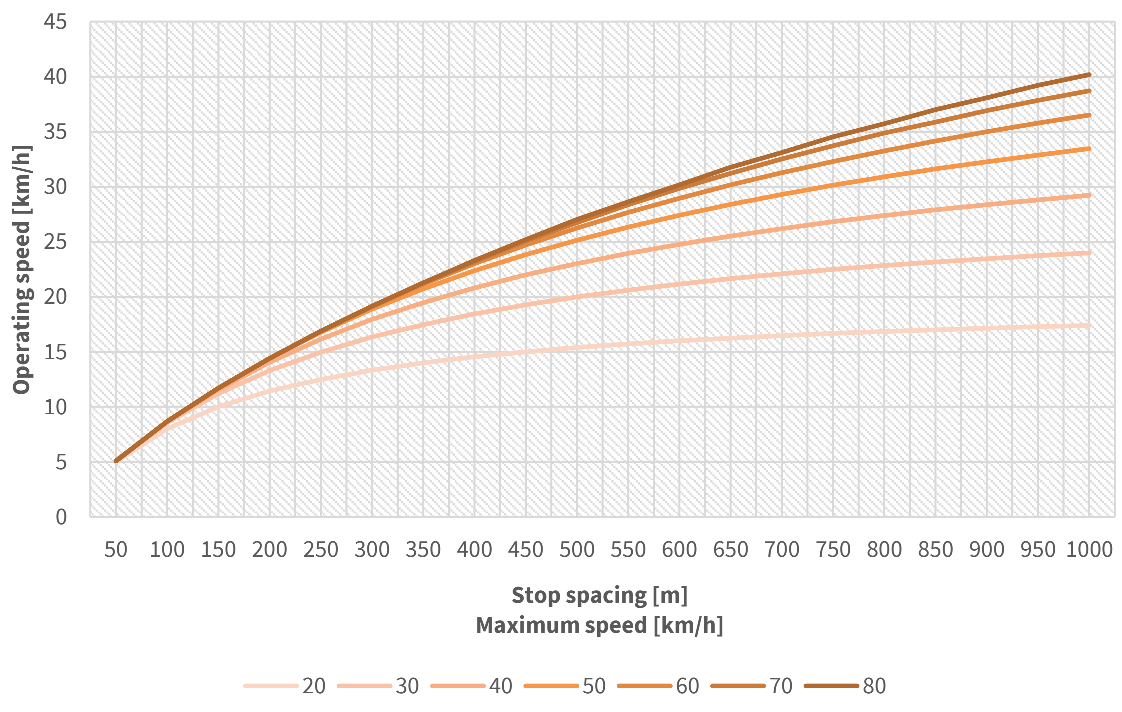
The exact capacities of vehicles are difficult to determine, as they are largely a matter of definition. As an example, Helsinki's current Artic trams have room for 199 passengers according to the manufacturer (Škoda Transportation a.s. 2020), but only 151 passengers for operational purposes (HSL 2016). Vehicle manufacturers may base their figures on densely packed standing passengers, perhaps to inflate the numbers for marketing purposes or because crush loads are an accepted condition in many cities. A true maximum capacity is also relevant for safety in an emergency.

Meanwhile, transit agencies design their service around more conservative numbers. Because passenger loads are rarely distributed perfectly evenly between vehicles on the line, HSL defines the capacity of a service based on vehicles which are 80–85% full. In the current network, most tram lines operate at a headway of 10 minutes, or 5 minutes for pairs of lines between major nodes. This is equivalent to approximately 1500 spaces per hour in each direction.

It is clear that if capacity alone is the determining factor for the technology used on a line, heavy rail is the optimal solution. However, new tramways in Helsinki will mostly be replacing buses on heavily used corridors. As some of the main radial streets in the city already serve in excess of 60 buses per hour per direction at peak times, and the city center terminals are at capacity (KYMP 2017a), there is little room for expansion. The comparatively larger unit size of trams can increase capacity while also achieving more reasonable frequencies.

3.3.2 Operating speed

Figure 12. Operating speed of a rail line as a function of maximum speed and stop spacing.



The graph in figure 12 is based on a highly simplified simulation model. Acceleration and deceleration are assumed to be a constant 1.0 m/s^2, which literature suggests to be a comfortable level for standing passengers (Powell and Palacín 2015) and is easily achieved by modern trams. Dwell time at stops is assumed to be a constant 20 seconds, which is sufficient for passenger operations at all but the busiest interchanges, or in cases where the wheelchair ramp is deployed. According to one set of measurements, the mean duration of stops by trams in Helsinki is 16 seconds, with 20 seconds covering approximately three quarters of all instances (HSL 2017, p. 18).

Despite these simplifications, the model clearly demonstrates a key fact: in urban conditions, the maximum permitted travel speed is not the most significant factor contributing to the average speed achieved in service.

In street operation, trams generally follow the same posted speed limit as other vehicles (Peltola 2018). In Helsinki, the limits vary in most cases from 30 km/h on quiet residential streets to 50 km/h on major arterial streets. Vehicle traffic in designated pedestrian zones is limited to 20 km/h. At the upper end, trams can reach speeds of up to 70 km/h on dedicated rights-of-way. Further work is needed to determine exactly what level of physical segregation from other nearby modes of transport is necessary to allow this.

Even higher speeds are technologically feasible – for example, Helsinki's Artic trams have a design speed of 80 km/h (Škoda Transportation a.s. 2020) – but have been deemed unnecessary. German regulations require the use of a train protection system at speeds above 70 km/h (BOStrab § 49). In the absence of local legislation, this rule appears to have been adopted as the basis of design guidelines in Finland. Traveling faster would therefore add considerable complexity to the system, for a very minor benefit.

Assuming a 500-meter distance between stops, as suggested by current planning guidelines (HKL 2018), the operating speed will only increase by approximately one third (from 20 to 27 km/h) while the speed limit more than doubles from 30 to 70 km/h. At a stop spacing of 800 meters, which is advertised to the public as a *pikaraitiotie* design feature (KSV 2015), the differential still does not rise above 60%. There is simply no time to accelerate to a very high speed between stops located so close to each other.

In practice, these results represent something of an upper bound. Although the ideal in tram operation may be smooth acceleration and coasting from one stop to the next, trams in Helsinki are not particularly well protected from the impact of other traffic. On parts of the current network, trams are still stuck in mixed traffic (ROW C), or in such narrow lanes that dynamic lateral movements risk scraping neighboring large vehicles (ROW B, technically). A need to slow down thus occurs quite regularly.

Waiting at traffic signals or pedestrian crossings is also a common event. Even with hypothetical perfect signal priority, trams might interfere with each other at major intersections. Following a strict schedule in the operation is essentially impossible due to human factors, which further complicates any prioritization measures as compared to a fully segregated system. Nevertheless, reducing the frequency of unscheduled stops and slowdowns is likely one of the most effective ways to begin increasing operating speed. (HSL 2017.)

As the stop spacing increases, the speed curves approach their respective maximum speeds asymptotically. However, stop spacing must be on the order of several kilometers before maximum speed becomes the dominant factor in determining operating speed. For an urban tramway, such considerations are all but irrelevant. Across the currently planned network in the Helsinki region, there are only a handful of stop pairs separated by even a single kilometer. All such cases involve crossing a body of water or protected parkland.

A tram-train utilizing mainline railways for more regional service could actually benefit from a higher top speed and must be equipped with additional safety systems in any case. Helsinki does not appear to have use for tram-trains in its transit system, as railways in the area are already near capacity with full-size trains. They remain a potential solution in certain smaller cities with underutilized railways nearby. (Kiviniitty 2019.)

Table 3 compares operating speeds achieved on various lines in practice:

Table 3. Comparison of scheduled operating speeds and rights-of-way of selected rail lines in Helsinki and other cities.

Line	Length [km]	# of stops	Avg. stop spacing [m]	Scheduled run time [min]	Operating speed [km/h]	ROW category [% of total]		
						A	B	C
Helsinki								
Line 4 Katajanokka - Munkkiniemi	7.9	23	360	30…35	14…16	0	70	30
Line 9 Jätkäsaari - Pasila	7.5	24	330	30…40	11…15	0	50	50
Kruunusillat Rautatientori - Yliskylä	9.0	15	640	*24*	*22*	25	70	5
Raide-Jokeri Keilaniemi - Itäkeskus	24.6	34	750	*61*	*25*	25	70	5
Metro M1 Matinkylä - Vuosaari	29.7	22	1410	41	43	100	0	0
Local train K Central Station - Kerava	28.6	15	2040	34	50	100	0	0
Other cities								
Tampere line 3 Pyynikki - Hervanta	11.4	19	630	*30*	*23*	20	60	20
Bergen line 1 Byparken - Airport	19.9	27	770	43	28	70	25	5
Stockholm Tvärbanan Sickla - Solna	19.0	26	760	50…57	20…23	60	25	15
Tallinn line 1 Kopli - Kadriorg	8.2	20	430	25…28	18…20	0	90	10
Strasbourg line A Illkirch - Parc des Sports	14.7	28	540	44…48	18…20	10	85	5

Schedules of existing services represent the situation in August 2020, as available publicly from the transit agencies of the respective cities. For lines not yet in operation, the run times are based on publicly available plans and shown in cursive. The proportions of ROW categories as a percentage of total line length are rounded to the nearest 5%, as it is often difficult to determine exactly where the infrastructure changes between categories, and no detailed statistical analysis is performed on the data.

Each case has been selected purposefully. In Helsinki, the routes of lines 4 and 9 are unaffected by major construction works at the time of writing, so they should be performing as planned. Furthermore, line 4 has remained largely unchanged for several decades and utilizes the full variety of existing tramway infrastructure. Line 9 is perhaps the last example of the “pre-modern” tramway planning philosophy, running on several sections of ROW C purpose-built as recently as 2008. On the contrary, Kruunusillat and Raide-Jokeri are currently in progress as the first examples of the rapid tramway paradigm. The metro and local train lines serve purely as points of comparison to the service heavier rail infrastructure allows.

Tampere is building Finland’s first brand new tramway system in more than a century and should serve to show what is possible in fundamentally the same environment as Helsinki but with less historical path dependence. Stockholm and Bergen likewise exist in a similar Nordic context (in terms of legislation and climate) and have opened new tramways in recent decades. These have likely served as partial inspiration for the plans in Helsinki. Tallinn’s tramway system is of a similar age as that of Helsinki but developed even less during the Soviet era. It has only recently seen some modernization. Finally, Strasbourg has one of the best-known examples of a newly built tramway system in Central Europe, originally opening in 1994. Of particular interest is the stop spacing, which is very close to the 500 m recommended by current guidelines in Helsinki.

Although the data is not fully representative, some observations can be made. Above all, the operating speeds of the existing tram lines in Helsinki are extremely low, as has been established previously.

There is significant variance in the scheduled running times between different times of day on many of the lines. This is particularly evident on Helsinki’s line 9, where the longest run time is longer than the baseline by one third! The metro and local train lines are naturally much faster due to their wide stop spacing and high top speeds, but it is perhaps even more important that their operation is consistent due to fully segregated ROWs.

Stockholm’s Tvärbanan also shows a significant variance, despite running on a grade-separated ROW A for more than half of its total length. Bergen’s light rail seems extremely similar on the surface but achieves considerably higher speeds and a steady schedule. The only notable difference is indeed an even lower percentage of the length of ROW C. Uncontrollable delays on short on-street segments appear to affect reliability disproportionately, and therefore they must be accounted for in schedules at times of heavy traffic. This further highlights how important it is to segregate trams from other traffic where possible.

3.3.3 Walking distance to stops

When analyzing the coverage of stops on a line, the most common approach is simply plotting circles of uniform radius atop each stop. A typical radius for these circles is 400 meters, or the nearly identical quarter mile in an American context (El-Geneidy, et al. 2014). This represents the approximate distance which most able-bodied people are willing to walk to access transit service. The area within the circle is then considered in estimating the impact of the service. In Helsinki, one rather concrete effect is that the distance to rail transport partly determines the number of parking spaces required from new development. However, there are several reasons why a more nuanced approach might be preferable.

Firstly, the circle does not correspond to the actual walking distance between each stop and surrounding destinations. It is not typically possible to follow a completely direct trajectory in an urban environment. Each twist and turn introduced by the available network of pedestrian paths reduces the straight-line distance accessible from the stop by walking a fixed total distance. Obstacles such as a shoreline or an arterial street without frequent pedestrian crossings can further compound the effect.

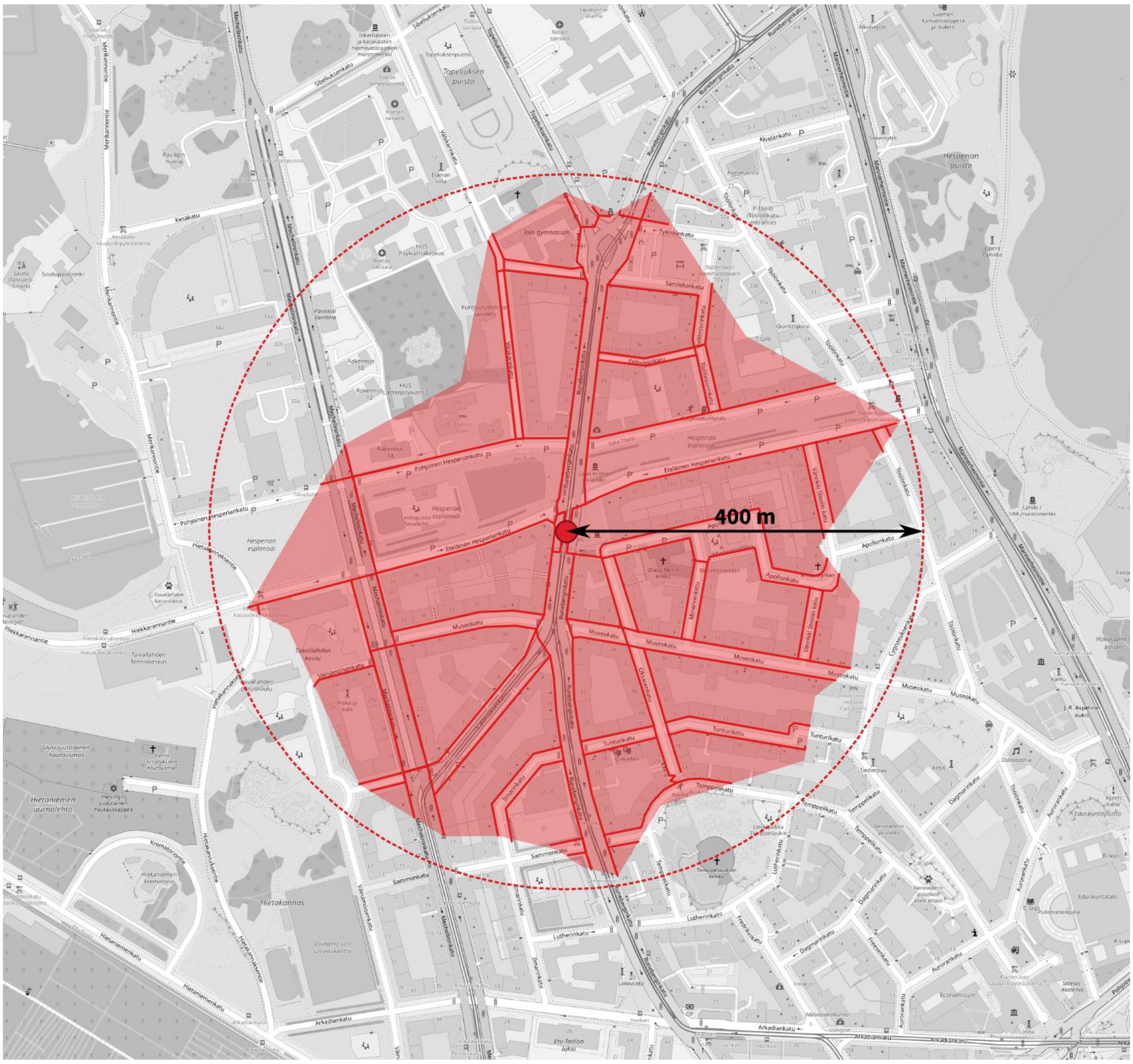


Figure 13. Illustration of difference between uniform radius and actual walking distance. Case Apollonkatu, Helsinki.

Figure 13 presents a case study centered on the Apollonkatu tram stop in Töölö, Helsinki. The dashed circle represents the simple 400-meter radius. The solid lines follow legal pedestrian routes and together form the irregular shaded area which is actually reachable by walking 400 meters. In this instance, the shading covers 68% of the circle. Exact numbers will vary case by case, but it is clear that the circle always overestimates actual coverage, often by a significant margin.

Furthermore, tram stops and destinations are not point objects without dimensions of their own. A full-length platform with ramps following the design manual is over 70 meters long and typically accessible only at the ends (particularly with ROW B island platforms). Given that the overall acceptable distance is some hundreds of meters, the platform alone can account for ca. 10–20% of the walk, depending on factors such as which door of a tram is used. Distances of similar magnitude can likewise be found within larger buildings which passengers may be traveling to or from. Platforms serving opposite directions at the same stop are not located at exactly the same position, either. Overall, there is so much variability that some level of simplification becomes unavoidable.

On the other hand, basing the analysis on a precise fixed distance in the first place is a source of error. Passengers are people with individual preferences and requirements. For example, some might be happy to walk much farther than average because it provides healthy exercise, while others have such difficulty walking due to age or illness that they can barely cover any distance. Even the very same person might be more willing to walk than average when the weather is pleasant, or less willing when they are rushing to an important meeting. Finally, the availability and quality of transit service in itself affects how long a distance is acceptable (El-Geneidy, et al. 2014).

The overall walkability of the built environment also increases the distances people will walk on average. This is difficult to define and measure exactly, but Speck (2012) outlines four main conditions which favor walking: it must be *useful*, *safe*, *comfortable* and *interesting*. Usefulness is a relatively simple concept and ties directly into distances – walking should help a person get where they want to go. If walking all the way would take too long, as is often the case in a large city, transit can complement it. (Likewise, transit is essentially always complemented by walking.) A walk becomes even more useful if it can serve multiple purposes at once, such as visiting a grocery store as part of a commute back home. The other three conditions are more subjective and beyond the scope of this thesis. In brief, it can be concluded that distance alone does not determine how enticing it is to walk somewhere.

Due to all of these factors, deciding where to build stops is not a trivial task, but it is important for the resulting service. The recommended stop spacings of 500 meters for urban and 800 meters for rapid tramways should be treated as only a general guideline and not strictly adhered to in every case.

3.4 *Stages of tramway planning*

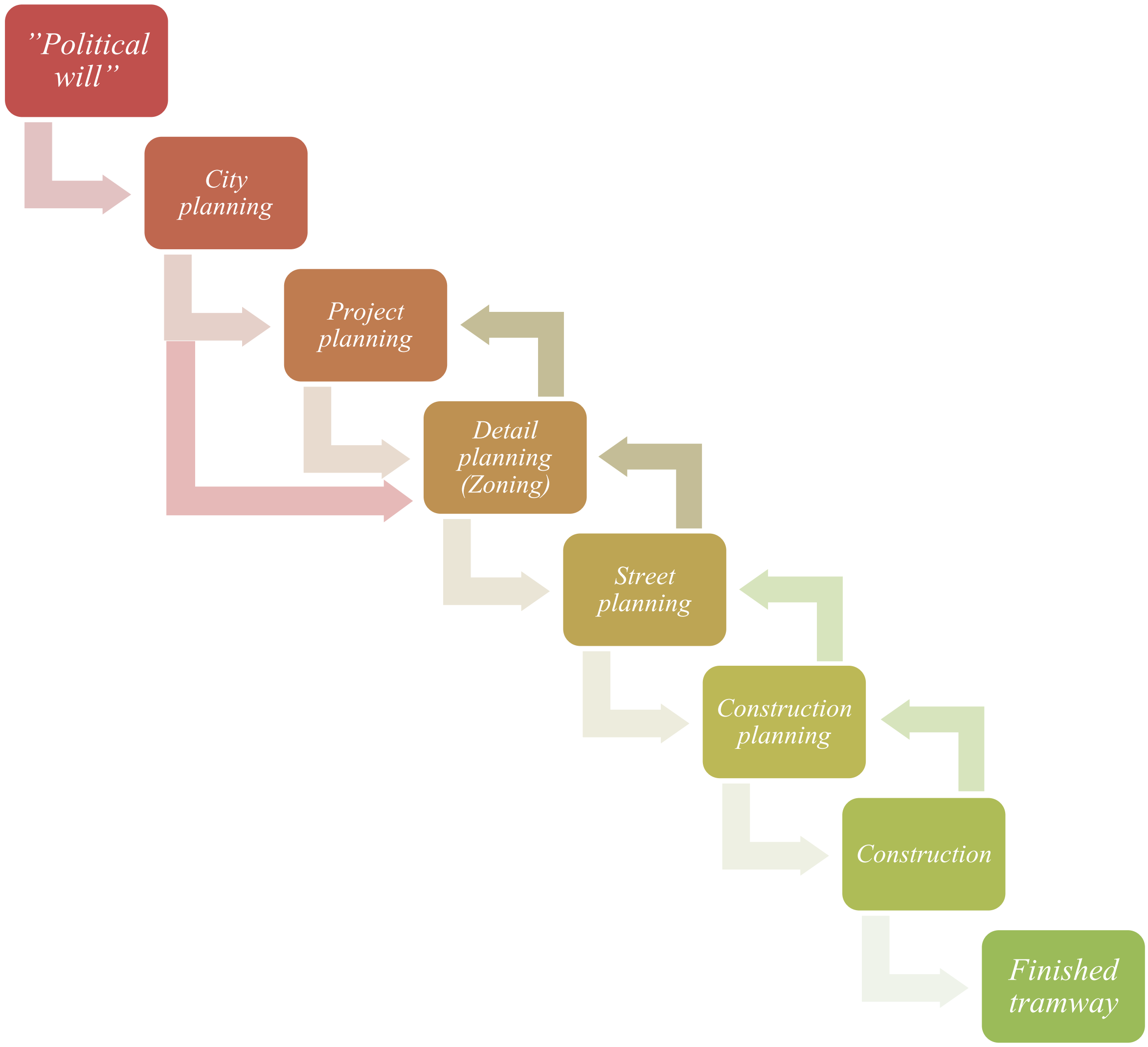


Figure 14. A simplified diagram of the process by which a new tramway is constructed in Helsinki.

It is difficult to define an exact process for infrastructure planning, particularly as different projects appear to follow their own paths. Nevertheless, the above diagram shows a rough hierarchy. There are many feedback loops between consequent stages, but as time goes on, certain features get locked down and returning further back becomes unfeasible. In the end, a strong path dependence usually determines the final result.

3.4.1 Political decision-making

The beginning is the most nebulous and unclear stage. Attempting to define the precise origins of each tramway project is a task far beyond the scope of this thesis. However, it is clear that a project does not come into existence from a vacuum. Someone, somewhere, has an idea which is refined in informal conversations among acquaintances, often over the course of years, before eventually surfacing in the official processes of local politics. According to Kivekäs (2019), the entire rapid tramway concept originally emerged on online discussion boards dedicated to urban planning and transit.

In the Finnish land use planning system, municipalities have the final say in any planning or construction within their boundaries, which is sometimes referred to as a “planning monopoly.” Therefore, any new infrastructure must be approved by municipal authorities and political decision-making bodies. If the idea originates from residents who are not closely involved with the system, they might submit a formal petition signed by interested people. A recent example is the *Science Tram* campaign, where local student associations proposed the construction of a tramway linking the various higher education campuses in the area and collected over 4,000 signatures from residents. The idea received publicity and may have played a small role in the 2017 municipal election in Helsinki. (World Student Capital 2019.)

More commonly, projects can be traced back to earlier plans which have evolved over time. For instance, the original plans for a metro network in Helsinki have likely served as the basis for some currently proposed projects. Most of the lines have not been realized in any form beyond buses even six decades later, even though passenger demand has only increased on the same key corridors.

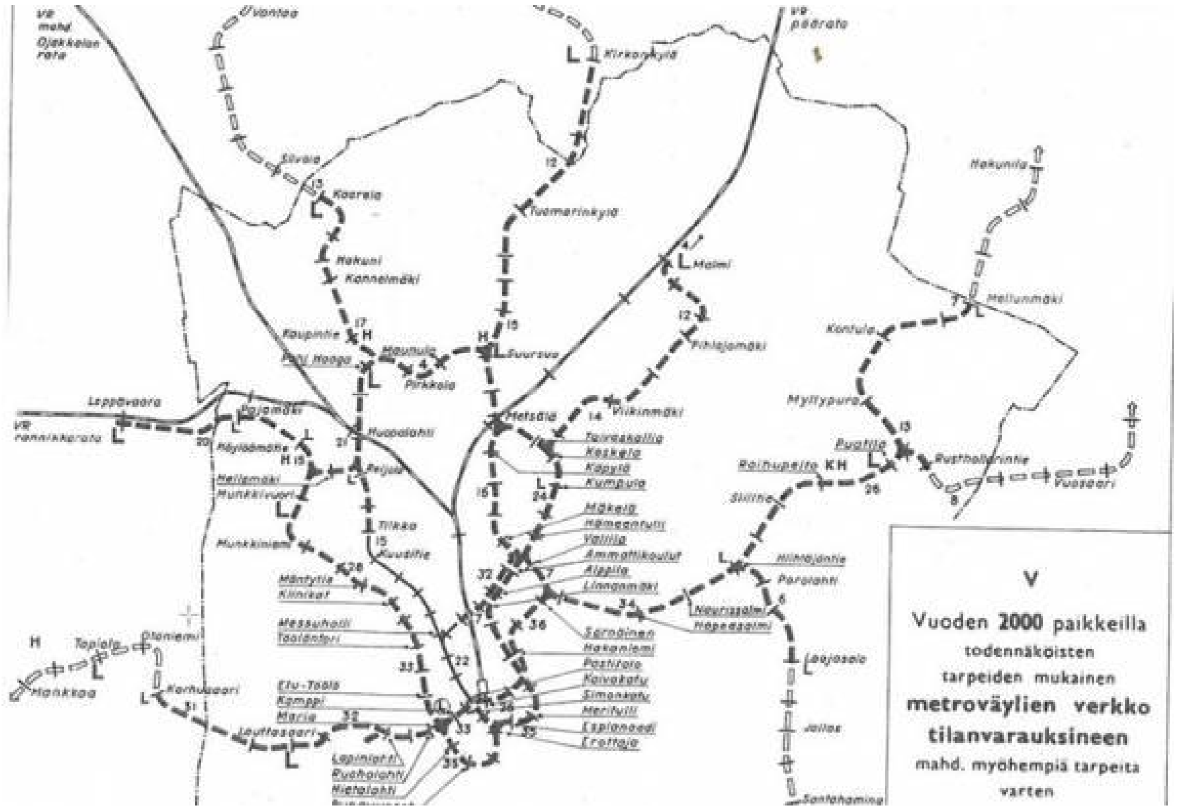


Figure 15. Metro network proposed for Helsinki in 1963. The technology would have been similar to modern tramways. (Source: HSL.)

The first major modern tramway project in the region, Raide-Jokeri, is also based on increasing demand. The first official plans for the line were published already in 1990, but building a new tramway appears to have been politically impossible at the time. Service eventually begun with buses in 2003, using a purpose-built busway for a part of the route. Passenger numbers on the orbital line exceeded expectations and eventually it became clear that it must be upgraded to a tramway purely for capacity and reliability.

However, since converting the line from buses to long trams can approximately triple the capacity, there is even some room to increase demand for the service. More than being pure transit projects, rapid tramways enable new construction along the lines without jamming up the existing transport network. This is vitally important to achieve the goals of densifying the city set out in the master plan. Indeed, new land use potential was one of the primary reasons for the focus on tramways in the plan.

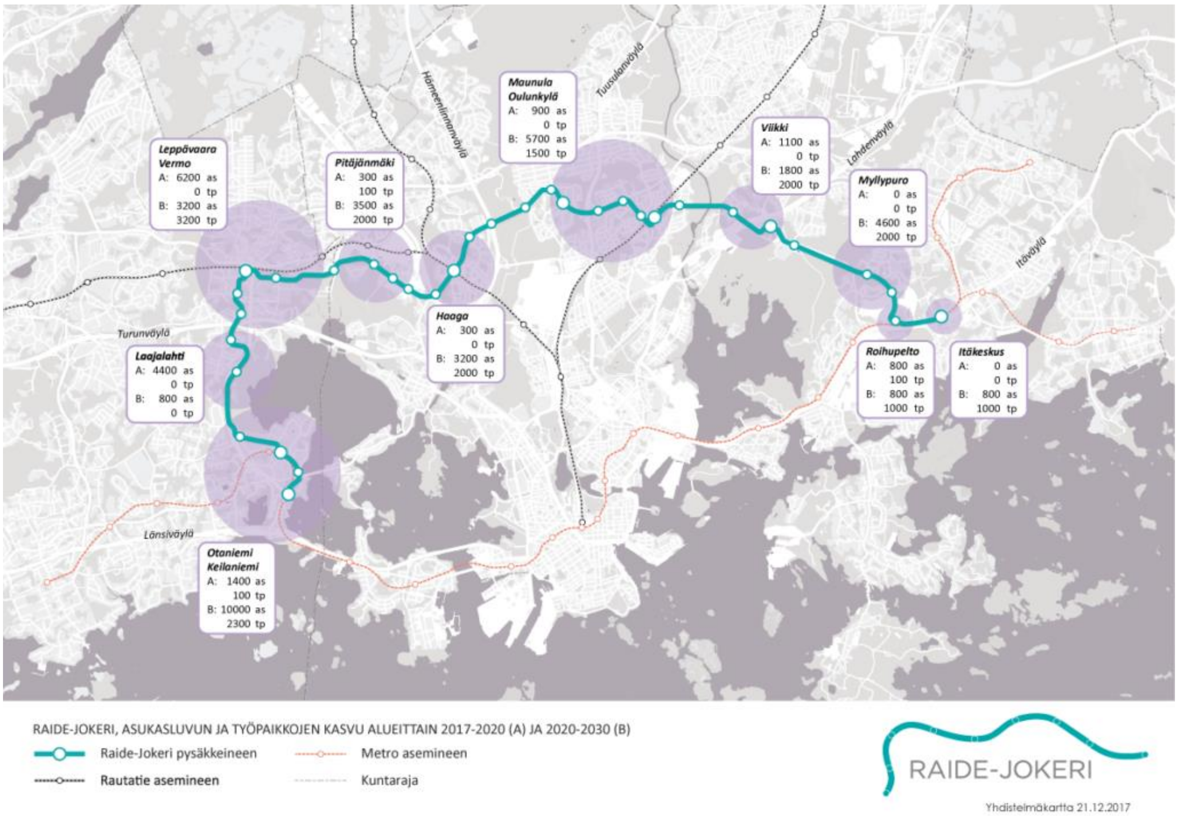


Figure 16. Increased land use potential along the alignment of Raide-Jokeri. (Source: Raide-Jokeri project.)

When suggestions and decisions are made at this stage, they are primarily questions of values. Politicians are usually not interested in technical details; what matters is that there will be “more transit” or “more housing.” Although on the contrary, sometimes the discussion does get hung up on irrelevant details – layman understanding easily focuses on specific kinds of vehicles or infrastructure rather than abstract measures for level of service.

The general values in the current planning paradigm appear to have been set already. Transport modes are in principle prioritized in the order walking – cycling – transit – cars. Given this order, it is curious that there does not seem to be any specific focus on walking in the transport planning of Helsinki. It is merely always present. On the contrary, cycling and tramways (as a subset of transit) have received major attention over the past decade compared to earlier principles. This may be partly because they complement each other well. Either one alone might not provide enough political pressure to result in new infrastructure. Together they are a reason to rebuild many of Helsinki’s major streets with better tramways and better cycleways in preparation for the coming densification.

3.4.2 City planning

Yleiskaavoitus

The Finnish land use planning system is in principle quite hierarchical, as defined in legislation (MRL § 4). At the very top are national objectives which aim to steer planning everywhere in the country in the same direction. They are strategic in nature and somewhat open to interpretation. The current objectives were set in 2017 and include themes such as “healthy and safe environment” and “efficient transport systems” (Ministry of the Environment 2018). The general idea of developing the transit network in a major city is certainly in line with these.

The next level down is the regional plan (*maakuntakaava*) which aims to ensure that nearby municipalities develop their land use and transport systems coherently and in line with each other. Preparing the plan is a highly political process as it is performed by committee members appointed directly by each municipality. Particularly for Helsinki, there is often a conflict between local and regional or national interests. Being the core of the region and capital of the nation, it provides vital services and jobs which must remain accessible from the outside, while the focus of the city itself is to densify and house a rapidly growing population.

Beyond this, each municipality prepares a master plan (*yleiskaava*) for their own area or parts thereof. The plan should adhere to the regional plan and define in closer detail how land use and transport will be arranged. However, by its nature, the plan will remain somewhat vague. Neither the spatial nor temporal scales involved allow a high degree of precision; the plan should account for development of the whole area several decades into the future. Helsinki’s 2016 master plan is based on a scenario for 2050.

Figure 17. Excerpt from the primary map of City Plan 2016. (Source: City of Helsinki.)

If political decisions show what the general values are, city planning is where they get implemented spatially. The master plan now shows a vast number of corridors which are to receive heavy transit service. The lines have clearly been drawn with rapid tramways in mind but officially the service may e.g. be started with buses, similar to the case of Raide-Jokeri.

3.4.3 Project planning

Hankesuunnittelu

After the general corridors are set in the master plan, they need to be planned in more detail. While this is not officially prescribed anywhere, there does appear to be a general process now that the master plan is legally binding. A section of tramway between two major nodes in the planned overall network is extracted for further studying, aiming to increase the precision enough to form a basis for later detail plans.

Until the master plan was finalized, the ongoing projects (primarily Raide-Jokeri) were also feeding back to the preparation of the plan. Likewise, many of the tramways in the master plan pass through areas where existing detail plans do not leave much room for modifications. This demonstrates that the stages of planning are not rigidly hierarchical. However, in general, project planning fits between the master and detail plans.

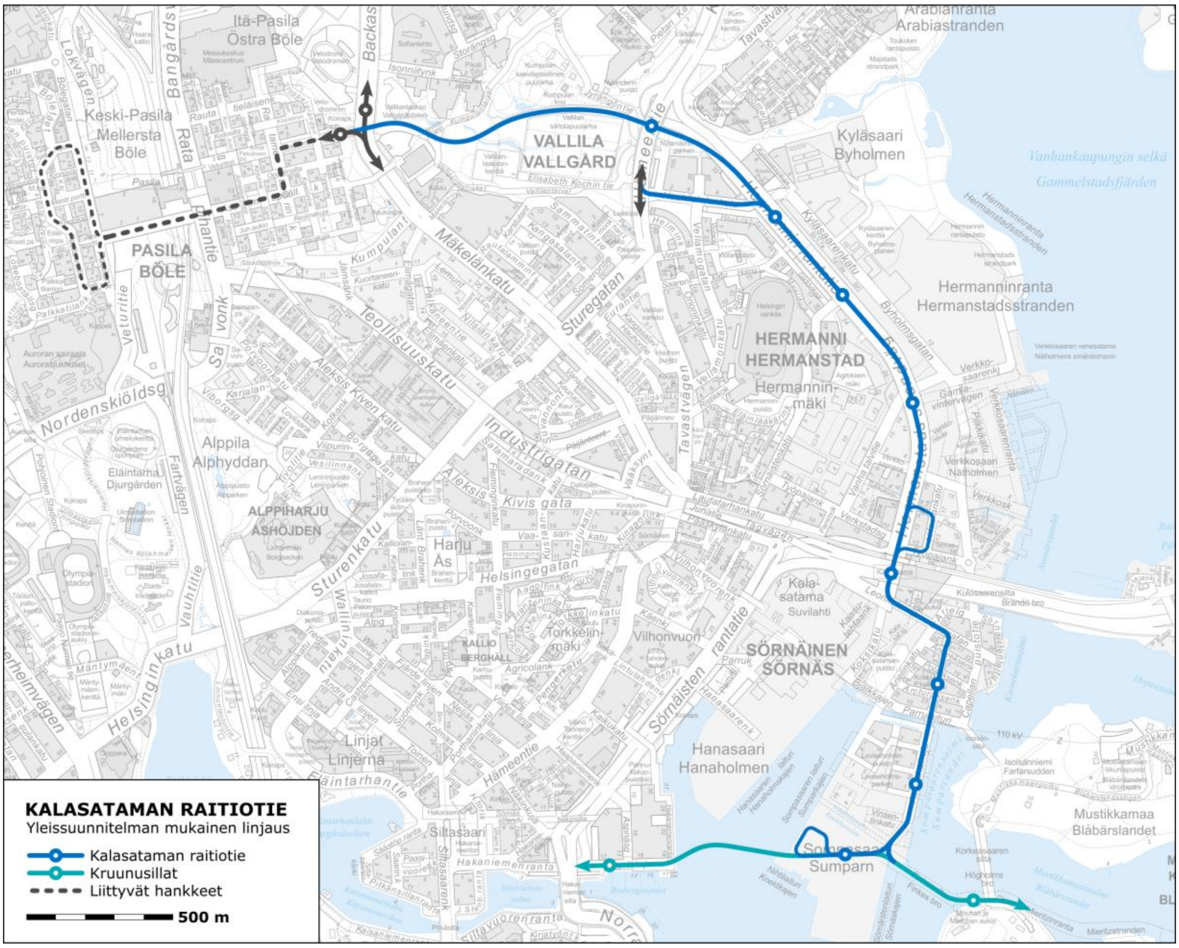


Figure 18. Alignment of the Kalasatama tramway in preliminary planning.

Although the corridors are already essentially fixed in many locations, there are also spots with a significantly higher degree of freedom for planning. In order to plan streets and buildings around the line, the general alignment needs to be locked down, with at most a few meters of ambiguity. Even more importantly, the locations of stops must be decided with the aim of maximizing the overall level of service. Once the plans have been narrowed down to a few variants, simulations can help in choosing the one which proceeds.

Since the City does not have nearly enough staff of its own for all of the planning work, the current practice appears to be that a separate project organization, consisting mostly of contractors from a private engineering firm, is established early on and keeps going to eventually produce the street and construction plans. Construction itself is outsourced in any case.

There are technically many different ways to handle the process juridically, but with tramways in particular, the *alliance model* appears to be in vogue. In a basic sense, it means that the client (City), engineering firm and construction company all pool their resources together for the whole duration of the project from an initial design all the way to start of operations. The primary benefit is (at least in theory) that innovations made at any point by anyone can be applied easily, as doing so will not get bogged down in contractual complications (Salamah 2017). Cost savings and overruns alike are shared between all parties. All three currently ongoing tramway projects in Helsinki use the model. Neighboring Vantaa appears to be bucking the trend and managing their upcoming tramway project in a more traditional fashion.

The largest problem at present is actually that there are this many tramway projects proceeding concurrently in Finland. As there was barely even serious discussion about them a decade ago, the country faces a serious shortage of engineers qualified for designing tramways. The topic is not taught in detail at any Finnish university or polytechnic, either. People involved with the current projects are learning on the job, but this will likely not be enough. By one unofficial estimate, there is a need for approximately 400 more professionals across the country in the medium term if all projects in the pipeline are realized. The only way to respond to this demand in time may be to recruit planners from abroad, which poses its own complications.

Another issue is that, at least up until now, each project in Helsinki has created their own design manual. Especially as they end up very similar by necessity, this wastes a lot of time on duplicated work. There is, of course, local precedent for this. The entire tramway system in Helsinki is quite “home-grown” and has design choices which stem directly from historical details. For example, the current design manual (HKL 2018) specifies transition curves with staggered fixed radii based on the capabilities of the old devices used to bend rails, rather than using a smooth clothoid shape. This did not suffice for Raide-Jokeri, so the project developed their own standards.

As Helsinki seems to be settling into a pace where two or three tramway projects are always active, it is critical to create one unified design manual usable for the entire network. The work has essentially already been done; all that remains is combining everything into one comprehensive document. There are also easily available international references such as the *Track Design Handbook for Light Rail Transit* (Transportation Research Board 2012).

3.4.4 Detail planning

Asemakaavoitus

In the Finnish land use planning system, one of the most important instruments is the detail plan (*asemakaava*) approved by the municipality. It defines the exact boundaries for zones of different functions in a localized area on the surface of the ground, generally up to some hundreds of meters across. The detail plan must follow the principles laid out in the master plan but slight deviations are possible, given that the entire purpose of the process is to add detail.

Although the vast majority of urban areas in Finland are covered by a detail plan, their exact contents vary significantly. While older plans might simply delimit built blocks and streets, newer plans particularly in the biggest cities often define the exact locations, sizes and construction standards of individual buildings to a rather extreme level of detail. In contrast, transport infrastructure still mostly gets allocated blank space with no further legally binding rules for planning.

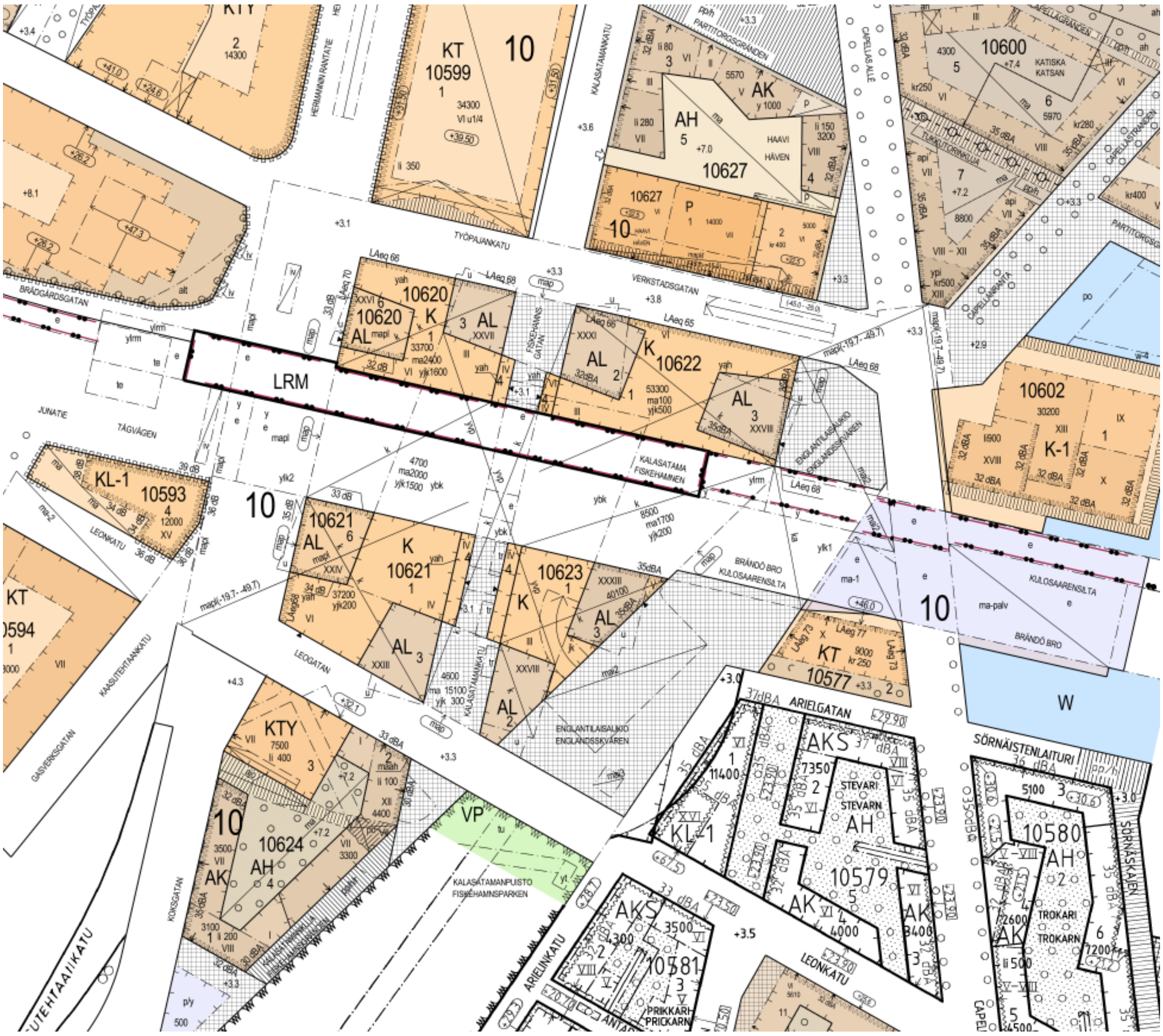


Figure 19. Compilation of detail plans in the Kalasatama area. Recently approved plans are officially stored in color, while older ones remain black-and-white. (Source: City of Helsinki.)

Deciding on the correct dimensions for said blank space is not a simple task. In essence, preliminary street planning should be done simultaneously with the detail plan to achieve good results. First and foremost, streets should not be made too wide. Some space is naturally required for the street to function for transportation at all. However, due to induced demand, lane capacity for private cars in particular tends to fill up, worsening congestion and pollution (Lee, Klein and Camus 1999). Adding width to individual lanes beyond the minimum required for vehicles to fit increases average speeds, even though in urban areas the aim is to restrict speeds for safety. Denser construction also naturally helps limit urban sprawl while still leaving space for greenery.

Beyond these arguments, there is a strong financial incentive to limit street space. Every additional built-up square meter means additional income for the municipality in the form of property taxes and land leases. The City of Helsinki owns 64% of all land within its boundaries (City of Helsinki 2019), an exceptionally high proportion even in the Finnish context. This has its roots in the era of Swedish rule, when the Crown granted ownership of large tracts of land directly to the then-small city, but is also a result of systematic land acquisition in the 19th and 20th centuries. Much of new urban development occurs on plots of city-owned land under long-term leases. (Yrjänä 2013)

On the other hand, making the streets too narrow causes difficulty fitting in all the required functions. Urban streets are not only thoroughfares for traffic but also provide room for utilities and act as extensions of residential and commercial space. As an example, street trees are widely seen as a desirable feature. However, their placement is restricted by both surface structures and underground utility lines. A single tree can require 25 m^3 of soil to grow in (City of Helsinki 2014) and spread a canopy several meters in each direction, which has significant implications for the dimensioning of streets.

Likewise, tram tracks should not lie directly above utility lines, as maintenance of the lines would then require stopping tram operations and rebuilding the tracks at significant cost. Additionally, the tracks themselves are not the only part of a tramway. Notably, the electrification system used in Helsinki requires either pylons or suitable nearby buildings to hang supports for catenaries from, as well as substations feeding a current to the lines at regular intervals. All of this should be taken into account for the detail plan.

Careful consideration is therefore required when allocating space for streets and other transport infrastructure, but the architects responsible for detail planning are typically not experts on transport. As a rough basis, there are standard cross sections of various types of streets. Additionally, transport planners are consulted at early stages in the process. While not legally required, separate transport plans (*liikennesuunnitelma*) depicting the layout of the streets are prepared together with detail plans in Helsinki. These are later used as the basis of more precise street plans (*katusuunnitelma*) which are defined in legislation (MRA § 41).

Including tramways in these plans is fundamentally a simple matter. The only crucial details are the width allocated for the tramway or its stops, as well as the radii of curves. Everything beyond these can and will be determined at later stages. As an example, the recommendation now is a minimum width of 6.40 m for a regular two-track tramway on a straight section of a street and 3.50 m for each platform at a stop (HKL 2018). This can easily be accounted for when determining how wide to make a street.

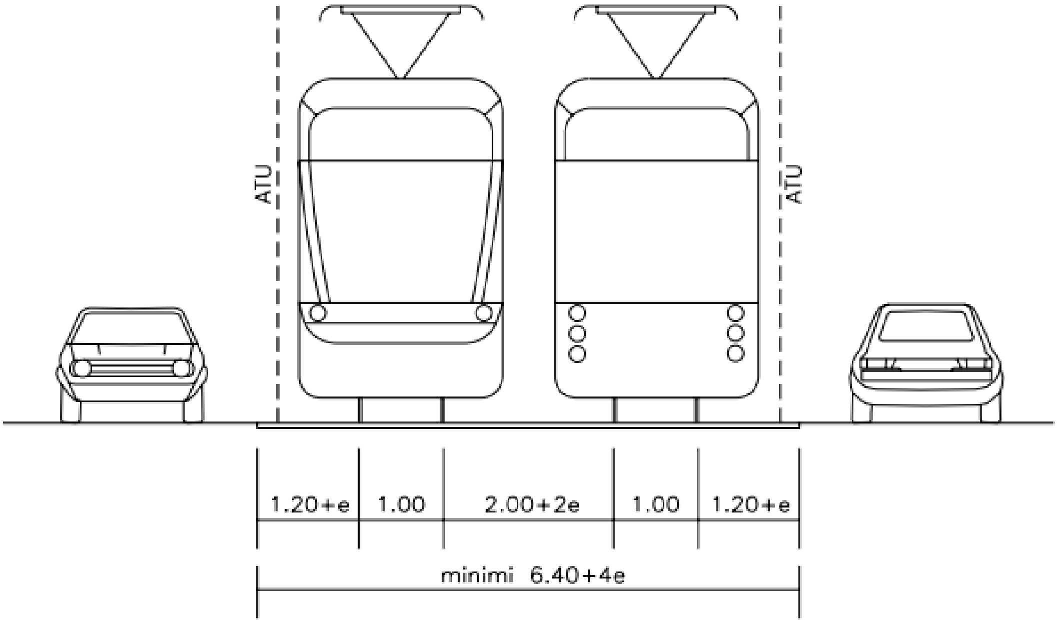


Figure 20. Default cross section of a tramway from the design manual (HKL 2018).

In practice, there appear to be some complications. Until quite recently, the standard has not been sufficiently wide. In comparison to the current target, many existing sections of tramway in central Helsinki are a full meter narrower at 5.40 m, which hardly provides any margin for dynamic movements or the encroaching side mirrors of vehicles on neighboring lanes. New street plans have been approved with 6.20 m for a tramway as recently as 2015. Considering that the 6.40 m guideline is supposed to accommodate even the roughest allowable dynamic movements, a slightly narrower space is probably enough most of the time. However, the aim is to eliminate problems stemming from narrow lanes entirely.

Some focus group participants brought up that the recommended dimensions have expanded a little at a time over several years as the desired level of service of tramways has increased. Until the design manual of 2018, there was little clear reasoning or authority behind the numbers. It has ultimately been up to individual planners to decide which of sometimes conflicting recommendations to follow, or where to compromise if an existing street cannot fit everything. This has been a source of some frustration.

The issue is hopefully now resolved for areas yet to be zoned. However, new streets will continue to be planned and built according to already approved detail plans for quite some time. There will no doubt be cases where space for a street has been allocated with a tramway in mind, but it is not actually sufficient for the current standards. This is particularly evident in intersections where the tramway makes a turn. Existing infrastructure has in some cases been built with extremely tight radii of barely over 15 m (e.g. the turn between Liisankatu and Snellmaninkatu in Kruununhaka), based mostly on the absolute technical limitations of rolling stock. The current recommendation is a radius of at least 35 m, which requires considerably more space around an intersection. If followed strictly, this would limit new tramways to wide arterial streets only.

A prime example of the issue can be found in Kalasatama at the intersection of Leonkatu and Junonkatu streets. Already constructed residential buildings encroach so close to the streets that a radius of only slightly over 20 m will be achievable, even though a tramway running through the location was described in the detail plan of the area. It is still entirely possible to build the line, but the tight curves will slow down operation and generate additional noise rather unnecessarily.

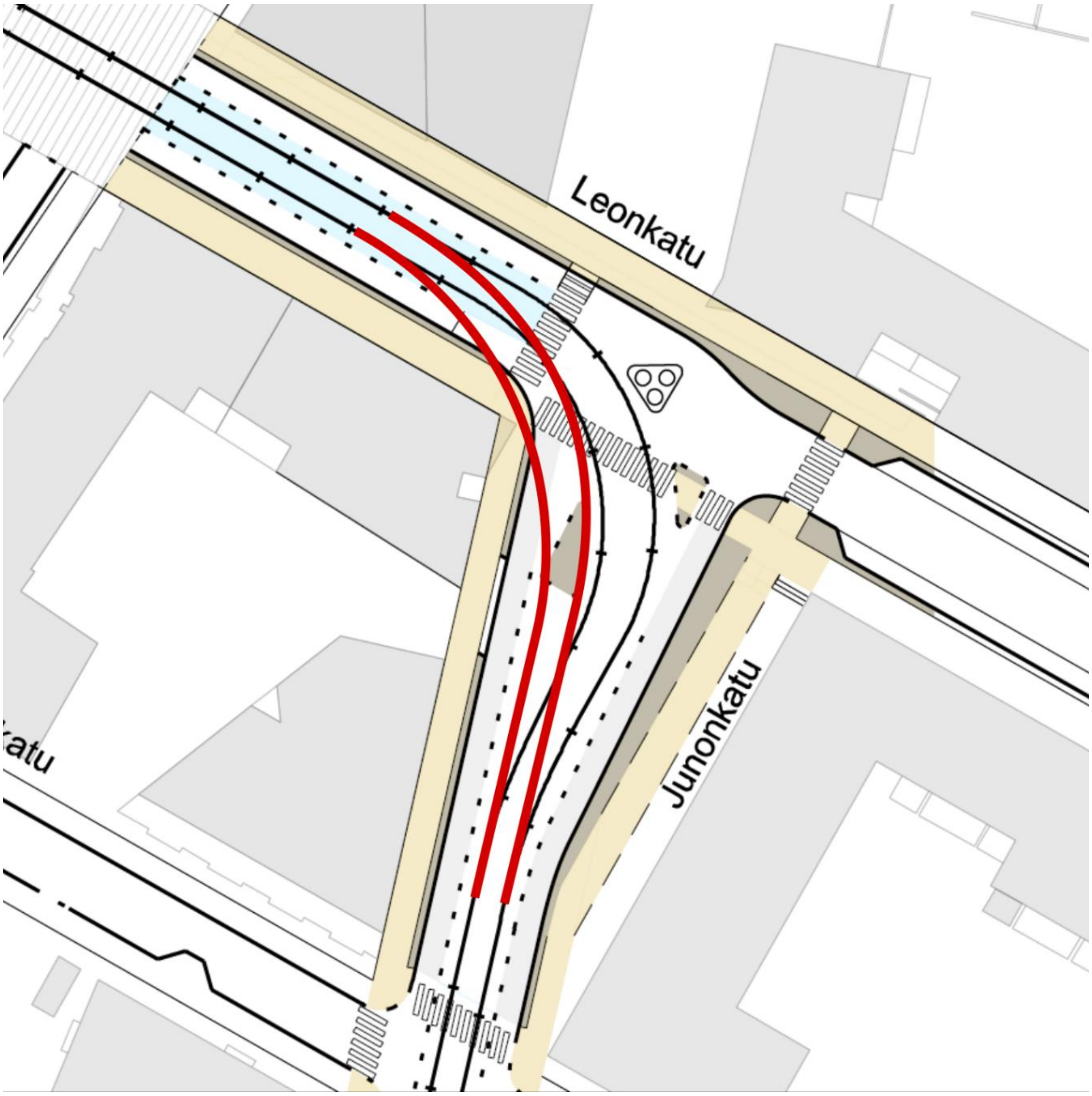


Figure 21. Excerpt from the preliminary transport plan for the intersection of Leonkatu and Junonkatu. The red lines represent an approximate alignment of tracks following current design guidelines, while the black lines underneath are the actually proposed solution. The gray blocks around the intersection are existing buildings.

3.4.5 Street planning

Katusuunnittelu

Following the detail plan, the last stage of the process with public oversight is the street plan. They are approved by the Urban Environment Committee for larger projects, which tramway construction is generally considered to be. The street plan defines the geometry and materials used for constructing the street to a relatively high degree of precision. They can be simple documents for small side streets, but this is rarely the case when tramways are involved. The alignment of tracks and positions of elements such as pylons for electrification must be finalized here, with only minor corrections possible later.

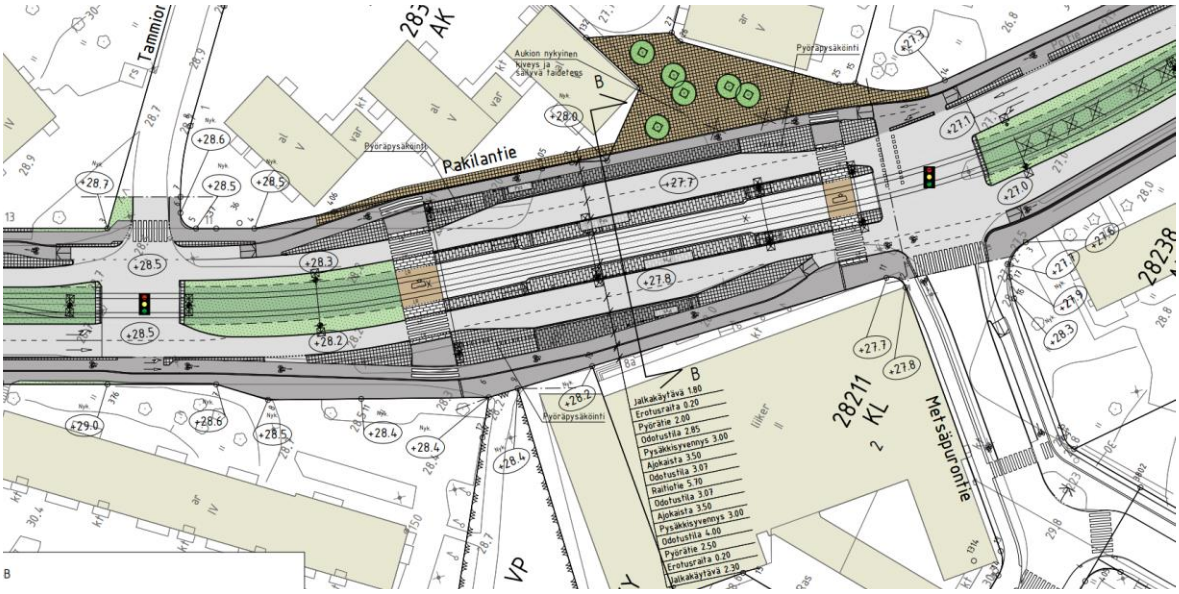


Figure 22. Excerpt from a Street Plan for the Raide-Jokeri project.

Similar to detail plans, the level of detail has increased considerably over the past decades. Street plans from the mid-20th century might simply consist of a horizontal alignment defined by a few coordinate points, a standard cross section, and a vertical profile along the centerline, all on one folded sheet of paper. Further details would be decided by the construction crew as needed. The basic principles remain the same today, but technological development has completely changed how the work is done.

At the time of writing, the process appears to exist at a somewhat awkward transition stage. Officially approved plans still consist of static 2D drawings, now PDF documents rather than paper. However, the documents are usually generated as automatic output from a digital 3D model of the entire project area, based on precise measurements of the terrain and existing structures. The model has a considerable variety of potential applications during planning, construction and finally maintenance.

For example, it is possible to calculate exactly how much soil will have to be moved, or automatically detect collisions between underground utility lines and optimize plans, before any physical work is begun. Updates can be distributed instantly without the risk of outdated copies remaining in circulation. During construction, the model can be used to electronically guide machinery with millimeter precision. Afterwards, measurements of the finished infrastructure can be verified against the model. Even later, the model can serve as a foundation for planning maintenance work. Unfortunately, many of these benefits remain hypothetical for the time being, and much of the software in use does not facilitate a very smooth workflow.

It is notable that producing street plans has been almost entirely outsourced by the city to private engineering firms. This has some implications for planning tramways in particular, as the transport planners employed directly by the city and involved in the earlier stages do not even have access to all the software used. Usually this does not pose a problem, but it effectively prevents detailed analysis of edge cases where a typical Transport Plan is not precise enough.

Taking the previously mentioned tight intersection in Kalasatama as an example, it could have been useful to model exactly how tracks will fit there after applying transition curves and what kind of path specific types of trams will sweep across while navigating the turn. The difference in an edge's horizontal position can easily be half a meter or more – not an enormous distance and difficult to determine manually, but certainly meaningful for the detail plan. Such analysis could also be outsourced, but this is contractually complicated to arrange for individual cases and not done in practice.

3.4.6 Construction planning

Rakennussuunnittelu

After the street plan has been approved, the details must be finalized before construction can proceed. Exact materials and positions have to be defined for everything, including e.g. utility lines, traffic signals, lighting, and signposts. One of the most important tasks is to ensure that the vertical geometry of the plans actually fits the surroundings in the physical world and works as intended for draining water. Since tramway projects are now largely related to new residential and commercial development, the plan area often borders other construction sites. Some tuning may thus be necessary.

Still, perhaps the most complex stage of the entire process is finally constructing new infrastructure in a pre-existing city which must continue operating the whole time. The occasionally heard analogies to open heart surgery are not entirely unwarranted. Tearing up and reconstructing a street temporarily reduces its capacity for transport and severely disrupts the daily lives of every resident and business in the immediate vicinity. Even if the work is necessary, public acceptance will probably not be unanimous. The problems can be somewhat mitigated, but not eliminated, with an effective public information campaign which begins well before the works themselves and lasts until they are complete.

On a broad level, this means it is not feasible to carry out work simultaneously on multiple major street corridors located close to each other. The effects on the surface transport network are far-reaching. Reduced lane capacity on one segment can create long queues or shift much of the demand to a parallel route. Rail transit is particularly vulnerable to disturbances, as even a small cut in the track can result in diverted or suspended service several kilometers away. One of the advantages buses have over trams is their ability to follow diversions together with other road vehicles. Despite this, the level of service will suffer from temporary infrastructure which is not built to normal standards and changes on a weekly or daily basis.

As an example, the reconstruction of Hämeentie has sent four of Helsinki’s ten tram lines to modified routes for a period of over a year. Whereas the normal network splits the four lines entering the Kallio area from the south across two streets, all of them currently follow the same route. This actually improves service at a handful of stops, although the doubled frequency sometimes results in trams having to wait to fit alongside a platform. Elsewhere in the affected area, lines are using tracks which normally see no revenue service at all. However, the stop spacing is likely too sparse here since platforms have not been constructed with regular use in mind.

Overall, passenger numbers on trams are lower than prior to the construction despite the capacity on individual lines remaining largely unchanged (Metsälampi 2020). This is a strong indication that spreading the service across a wider geographic area is beneficial, as long as headways at any one location do not increase too much. Analyzing the recovery after regular service patterns resume will unfortunately be challenging due to the wide-reaching effects of the Covid-19 pandemic.

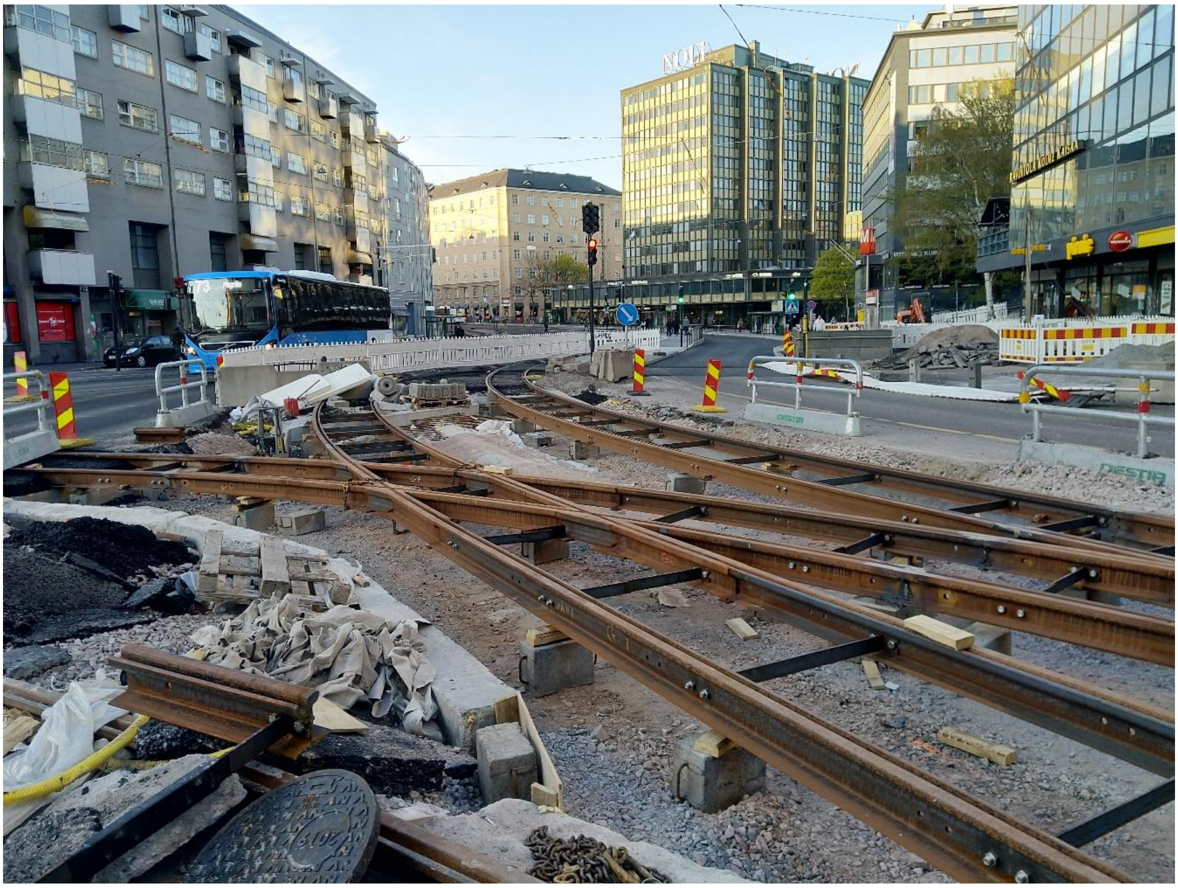


Figure 23. Tramway junction under construction. Hämeentie, Helsinki.

The case of Hämeentie will also not remain unique nor the last of its kind. Reconstruction of similar magnitude is already planned for essentially every other major street in the inner city. Scheduling them in a way manageable for the city, both as an organization and as a collectivity, is a complex process which does not leave much room for unanticipated additions. Although the final result for tram service should be improved speed and reliability, temporary disruption in some part of the network at any given moment appears set to remain the norm for years, if not decades. This will be necessary to account for in planning transit service.

On a local level, reconstruction of existing infrastructure must be planned very carefully. Interruptions to basic utilities like water or electricity in an occupied building are not tolerated for longer than a few hours. Emergency vehicle access must be ensured the whole time, and pedestrians should be able to reach any entrance. These factors severely restrict how works may proceed, as it is not possible to fully clear the space first and then build new structures from scratch. It is always simpler and thus also cheaper to build infrastructure before residents and services move into an area. The inner city of Helsinki is a particularly complex location, as many old utilities are poorly documented, and it is not even possible to plan work reliably in advance.

Since major construction works inevitably cause disruption, it would be beneficial to take the opportunity to do as much work at once as possible to avoid prolonging the issues. This has actually been the official goal in Helsinki since 2008 with the YKT (*yhteinen kunnallistekninen työmaa*) concept which brings the owners of utilities together to schedule their plans (City of Helsinki 2018). Nonetheless, much remains to be done in practice. One proposed model is a complete moratorium on reopening the surface of a street at the same location for some years after it has been sealed, which would force deeper cooperation.

The popularity of the alliance model for infrastructure construction may help a little, as it is contractually easier to expand the scope of joint work than renegotiate a predefined project with a supplier. This has been utilized to full effect in Tampere, where the tramway project has taken on renovating unrelated infrastructure on adjoining streets as well.

In particular, pedestrian and bicycle routes often suffer from construction. While emergency access with a fire truck requires keeping the street in a somewhat drivable condition for all vehicles, a sidewalk can be rerouted and torn up much more and still remain technically passable. From the perspective of the project, it may seem more important to facilitate construction as much as possible. Arranging better conditions for functions unrelated to the construction itself would increase the complexity of works even more, yet it would be in line with the stated prioritization of modes of transport.

4 Conclusions

Tramways are a versatile technology well suited to providing transit in a midsized urban area such as Helsinki. Although the existing network has a reputation of sluggish service limited to the inner city, it has potential for much faster operating speeds, higher capacity and wider coverage. The key is that infrastructure is planned and built for a certain quality of service, providing design parameters to target at each stage of the process. On this basis, the recent master plan includes several corridors of intensified land use served by new tramways.

Pikaraitiotie is first and foremost a brand. Technically there are almost no differences to the existing tramway network in Helsinki. The two systems will be mostly interoperable, and some sections of track will even see both types of trams in regular operation. Some new infrastructure will have category A rights-of-way, which can currently be found nowhere on the active tramway network.

The most visible difference is the new rolling stock, which will be longer, differently colored and bidirectional. The details of the branding are under development by HSL. Bidirectional operation is actually relevant for the planning of infrastructure, as turnaround loops will not be required on lines used solely by rapid trams. Since the trams have doors on both sides, there is also a possibility to use island platforms between tracks to save some space.

The first rapid tramway lines currently under construction or development will overall be built to slightly higher technical standards than old lines to facilitate smooth and fast operation. Budget permitting, the obvious action would be to adopt these standards on the entire network. At the very least, design standards should be unified for all future rapid tramway projects to avoid more duplicated work.

All of the important political decisions have been made over the past decade, and it appears Helsinki will be in a constant state of planning and building new tramways for a long time to come. However, there is a lack of skilled engineers for the job in Finland. More of them should be trained, or enticed join the projects from abroad. Unfortunately, it is not clear who specifically should act on this. A solution is unlikely to appear by itself.

Related to the thesis, the author has prepared two “cheat sheets” (in Finnish) based on the 2018 design manual to aid transport planners in drafting tramway alignments on the detail plan level. These can be found as appendices.

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List of Appendices

Appendix 1: Tramway design manual, summary. 1 page.
Appendix 2: Tramway design manual, graphical reference. 1 page.

Perehdy myös alkuperäiseen ohjeeseen. Varsinkaan rakennetuilla alueilla kaikkien suositusten noudattaminen ei aina ole mahdollista, mutta se tulee kuitenkin pitää tavoitteena.

- Raitiotien suunnittelun lähtökohtana tulee olla *sujuva ja häiriötön kulku* pysäkkien välillä.
- Raitiovaunuliikenne sijoitetaan pääsääntöisesti *kadun keskelle omille kaistoilleen*. Tämä parantaa edellytyksiä häiriöttömälle kululle ja yksinkertaistaa risteysjärjestelyjä.
- *Pysäkit* sijoitetaan risteysten yhteyteen tai muille keskeisille paikoille, suorille rataosuuksille.
- *Pysäkkien välinen etäisyys* jatkuvassa kaupunkirakenteessa on pääsääntöisesti noin 500 metriä. Tästä voidaan kuitenkin poiketa huomattavastikin olosuhteista riippuen.
- *Jyrkät kaarteet* ja *vaihteet* tulisi sijoittaa pysäkkien lähelle, jotta niihin ei jouduta erikseen hidastamaan. Kaarteissa ja niiden päissä kunkin raiteen molemmin puolin varataan *kaarrelevitys*.
- *Yhteiskaistat* linja-autojen kanssa eivät ole toivottava ratkaisu. Täysi *sekaliikenne* tulee kyseeseen vain hyvin vähäliikenteisillä katuosuuksilla.
- *Kadunvarsipysäköintiä* ei suositella raitiovaunujen käyttämän kaistan viereen.
- *Suojateille* tulisi järjestää saarekkeet ajoneuvoliikenteen kaistojen ja raitiotien väliin.
- Raitiotien yhteydessä *pyöräliikenne* järjestetään pääsääntöisesti reunakivellä erotettuna. Pyöräliikenteen tulisi voida ylittää kiskot vähintään 45 asteen kulmassa.

Geometrisen suunnittelun suositusarvoja

Lisätietoja ilmoitetuissa ohjeen luvuissa

Kaarresäteet ja kaarrelevitykset (e) [5.2, 5.4]	
Erillisradalla (≥ 50 km/h)	300 m (e = 0,0 m)
Katuympäristössä (≤ 40 km/h)	190 m (e = 0,1 m)
Risteyksessä (ilman siirtymäkaaria)	35 m (e = 0,4 m)
Risteyksessä (ilman siirtymäkaaria), *minimi*	28 m (e = 0,5 m)
Yksiraiteisen raitiotien kokonaisleveys [6.2]	3,4 m + 2e
Kaksiraiteisen raitiotien kokonaisleveys	
Tyypillisesti [6.3]	6,4 m + 4e
Sekakaistoilla [6.5, 6.6]	7,5 m + 4e
Pysäkkialueella [6.9]	5,5 m
Pylväiden tilavaraus [6.4, 7.1]	≥ + 0,7 m
Etäisyys raiteen keskilinjasta	
Rinnakkaisen raiteen keskilinjaan [6.3]	3,0 m + 2e
Rinnakkaisen ajokaistan reunaan [6.2, 6.3]	1,7 m + e
Jatkuvaan (> 9 m) kiinteään esteeseen [7.2, 7.3]	2,4 m + e
Katupuun keskipisteeseen [7.1]	3,5 m + e
Laiturin reunaan [8.3]	1,25 m
Pysäkin laiturialueen leveys [8.3]	3,5 m
Laiturin korotetun palvelualueen pituus [8.3]	
1–2 kaupunkiraitiolinjaa	30 m
2–4 kaupunkiraitiolinjaa	61 m
1–2 pikaraitiolinjaa	45 m
Päädyn luiska	+ 5 m
Pituuskaltevuus [4.3]	
Suoralla radalla	≤ 5 %
Pysäkillä tai vaihteessa	≤ 2 %
Pystysuuntainen pyöristyssäde [4.3]	1 000 m
Vapaa alituskorkeus [4.2]	6,0 m

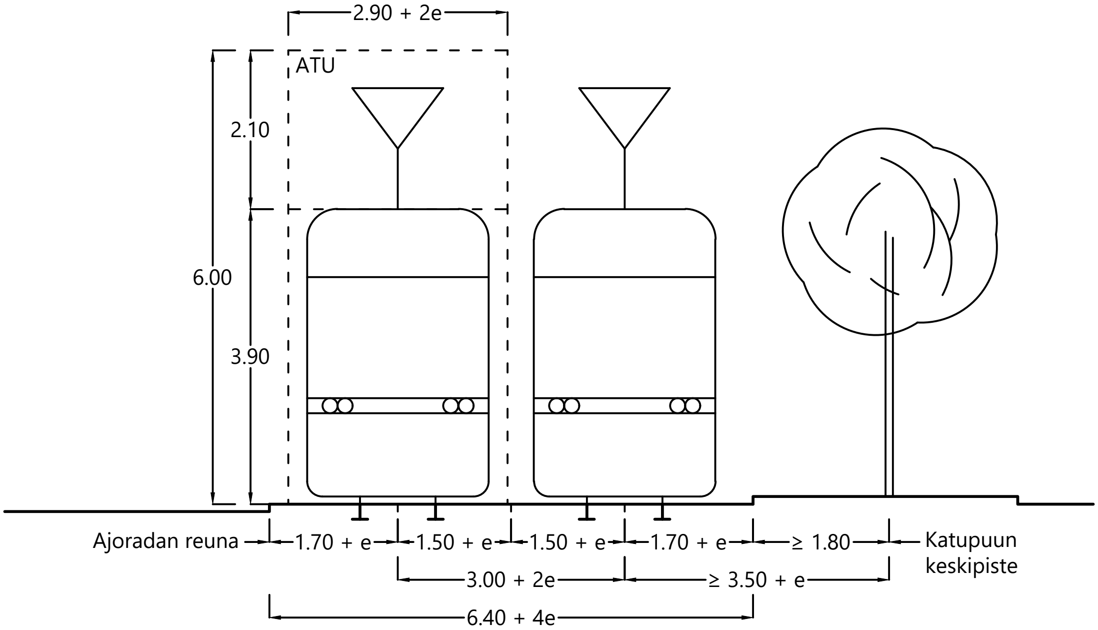
Raitioteiden suunnitteluohje 28.2.2018

Mallipoikkileikkaukset liikennesuunnitteluun (1:100)

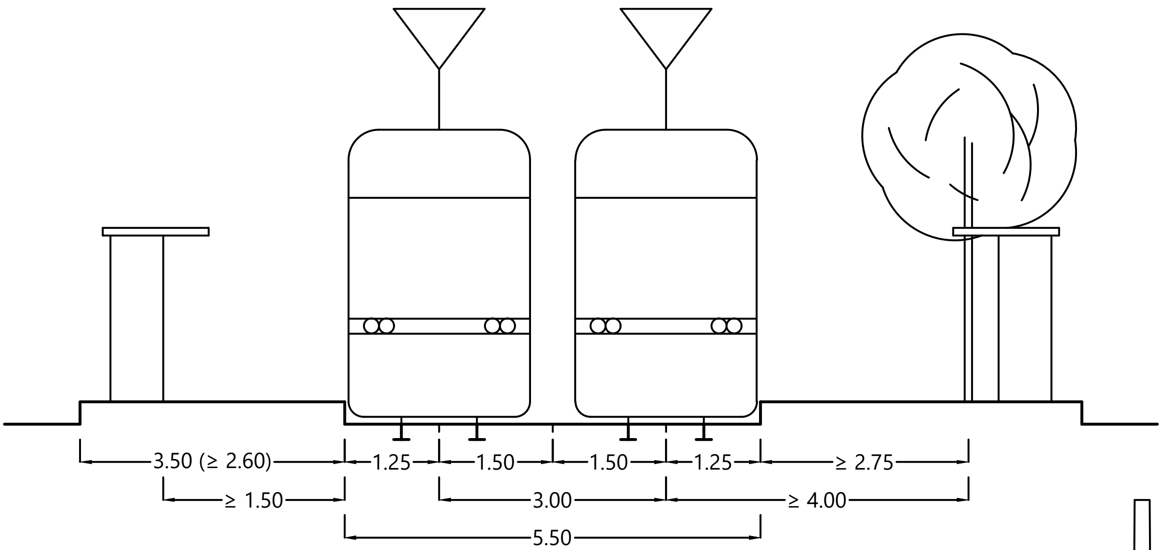
2.9.2019 HKL, Infra ja kalusto

Perehdy myös alkuperäiseen ohjeeseen!
Mitat ilmoitettu raiteiden keskilinjoista.
e = ATU:n kaarrelevitys (ks. luku 5.4)

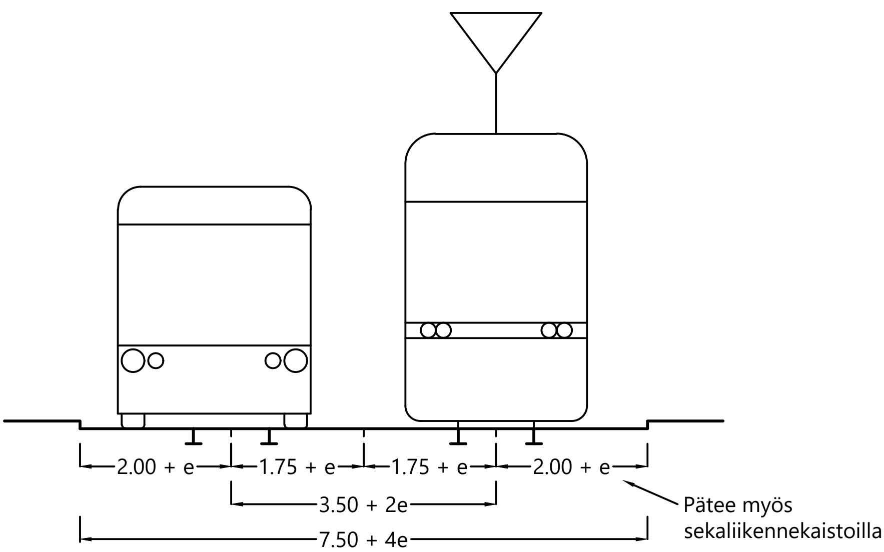
Tyypillinen raitiotie ajoratojen tai erotuskaistojen välissä



Pysäkkialueet (vain suorilla rataosuuksilla)



Yhteiskaistat linja-autojen kanssa (ei suositella)



Etäisyys esteeseen